White Pond Watershed Management Plan

Concord, Massachusetts

Supported from Concord Community Preservation Act funds

PREPARED FOR
Town of Concord
Division of Natural Resources
141 Keyes Road
Concord, Massachusetts 01742

PREPARED BY
ESS Group, Inc.
100 Fifth Avenue, 5th Floor
Waltham, Massachusetts 02451

www.essgroup.com

Final Revision May 29, 2015

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1.0 INTRODUCTION

ESS Group, Inc. (ESS) has prepared this Watershed Management Plan for White Pond on behalf of the Town of Concord's Division of Natural Resources (DNR). The objective of this Watershed Management Plan is to provide the Town of Concord (Town) with a framework that can be used to guide future management decisions related to White Pond.

This Watershed Management Plan provides the following:

- enumeration of primary pond management goals
- description of White Pond
- history of White Pond and its watershed
- assessment of the key physical, biological, and recreational resources of White Pond
- identification of key management issues that are currently impacting the pond and those that may emerge in the future
- assessment of Town-owned parcels in the White Pond watershed
- enumeration of primary pond management concerns
- prioritization of recommendations for the pond's future management

1.1 Management Goals

This Watershed Management Plan is centered around and driven the management goals for White Pond, which include the following:

- Improve water quality in the pond and prevent future algae blooms
- Provide managed recreational access to the pond and promote responsible public use
- Maintain a healthy aquatic ecosystem characteristic of an oligotrophic kettle pond

1.2 Acknowledgments

In addition to the DNR, the White Pond Advisory Committee (WPAC), Town Manager, and Dr. William Walker also provided useful guidance and feedback. Multiple Town offices were involved in supplying information critical to developing this Watershed Management Plan.

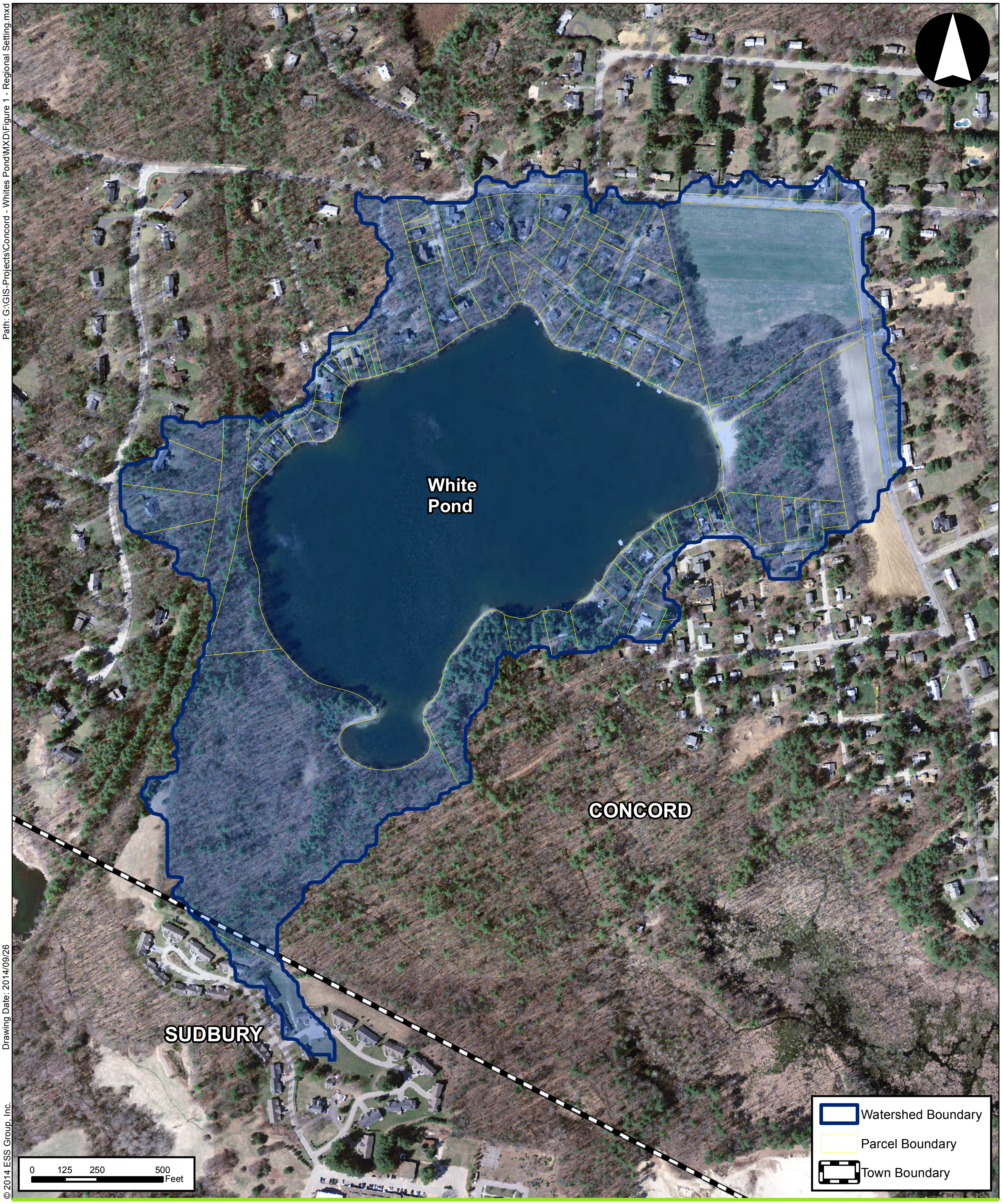
Input on this Watershed Management Plan was solicited from the public and incorporated. A summary of the comments received is included as Appendix A.

The White Pond Watershed Management Plan is supported from Concord Community Preservation Act funds.

2.0 SETTING AND HISTORY OF WHITE POND

Setting

White Pond is an approximately 40-acre Great Pond located entirely within the southern portion of Concord (Figure 1). The pond was briefly described by Henry David Thoreau in *Walden*, where he characterized the somewhat smaller pond as "the lesser twin of Walden." Like Walden, White Pond is a natural kettle pond with no perennial surface inlets or outlets. Water levels in White Pond regularly rise and fall several feet over multiple year periods but maximum water depths are typically in excess of 50 feet.



Path: G:\GIS-Projects\Concord - Whites Pond\MXD\Figure 1 - Regional Setting.mxd

Drawing Date: 2014/09/26

ESS group
environmental consulting & engineering services

White Pond
Concord, Massachusetts

1 inch = 500 feet

Source: 1) MassGIS, Towns, 2002
2) USGS, Aerial Imagery 0.3m, 2013

Location of White Pond and Watershed

Figure 1

As a kettle pond, White Pond's shoreline is relatively simple, forming an irregular reniform main basin with only minor coves. However, one larger cove, known locally as "Sachem's Cove," forms a nearly separate 1.5-acre basin at the southwestern margin of White Pond where water depths reach over 10 feet.

The majority of the White Pond shoreline and its approximately 113-acre watershed is occupied by year-round residences, formerly summer camps; large parcels of undeveloped land are present on the southwestern and eastern ends of the pond. The Office of Fishing and Boating Access hosts a public access cartop boat launch and small parking lot on the eastern end of the pond. Additional public shoreline access exists through land owned by the Town on the southwestern end of the pond. Privately owned parcels provide additional recreational access to White Pond for beach association members and neighborhood residents.

Stormwater flowing down the public access boat launch is partially captured by infiltrating catch basins. Water not captured by these catch basins is able to flow straight down to the pond.

White Pond's shoreline is essentially devoid of stormwater infrastructure. The primary exception is the presence of two leaching catch basins designed to capture and infiltrate stormwater runoff from the road leading to the public access boat launch.

The closest public wells are the White Pond Well, located just over 1,000 feet to the southeast of Sachem's Cove and the Jennie Dugan Well, located more than 2,800 feet to the north-northwest of White Pond. These wells are operated by the Public Works Department through its Water and Sewer Division.

The White Pond watershed is also surrounded by natural features that provide wildlife habitat, such as Dunge Hole Meadow to the southeast, Sudbury conservation land to the southwest, and a certified vernal pool. In most cases, these areas are connected to White Pond via undeveloped land that may serve as a wildlife corridor. The proposed Bruce Freeman Rail Trail passes by the western edge of the pond.

Geological History

Glaciation is predominantly responsible for the surficial geology of White Pond and its surrounding watershed. The most recent episode of continental glaciation, known as the Wisconsin Glacial Episode ended in the region approximately 12,000 years ago. During that period, large blocks of ice occasionally became isolated from the main ice sheet along the retreating glacial front. This process, coupled with surrounding sediment influxes and partial burial of ice blocks led to the development of a regional kame and kettle topography. As the ice blocks melted, they formed kettle ponds while the sandy kame and other glacial deposits became ridges around the ponds. White Pond is the result of such a process.

> "[P]erhaps the most attractive, if not the most beautiful, of all our lakes, the gem of the woods, is White Pond; — a poor name from its commonness, whether derived from the remarkable purity of its waters or the color of its sands."
> -Henry David Thoreau

Beneath the relatively young glacial deposits lies much older (420 to 360 million years before present) gabbro-diorite bedrock from the Devonian Period (USGS 1949). These rocks are close to the surface on the western side of White Pond but are buried under sandy deposits up to 140 feet thick on the eastern side of the pond (Walker and Ploetz 1988).

Human and Recreational History

Human impact in the White Pond watershed area was primarily limited to farming and logging until the 20th century. Humans first arrived in the Concord area between 8,000 and 12,500 years ago. Areas to the east and southeast of White Pond appear to have been used by Middle Archaic to Middle Woodland People (1,000 to 8,000 years ago) as hunting camps. European colonization in the 17th and 18th centuries converted at least some of the land near White Pond to pasture, orchards, and farm fields. By 1830, the presence of Powder Mill Road (to the north) and Plainfield Road (to the east) indicate greater volume of commerce in the White Pond area (known by then as Nine Acre Corner). By 1875, the Framingham and Lowell Railroad was operating just to the west of White Pond (Concord Historical Commission 2001).

Development in the modern sense of the word began near White Pond in the 1920s and 1930s. Platted subdivisions such as “Pine Knoll Shores” were laid out and dwellings primarily took the form of summer camps. Consequently, lots were extraordinarily small. By the 1960s a very high density of residences had been erected in some areas near the pond. This was accompanied by a steady increase in the number of homes converted from summer to all-year use (White Pond Reservation Task Force 2002).

White Pond’s status as a Great Pond dates back to English common law and the Colonial Ordinances of 1641-1647. These laws provide for the preservation of public pedestrian access to the water’s edge for fishing, fowling, and navigation, although Great Pond status does not necessarily require preservation of access for other public uses (e.g., swimming). To this end, petitions for enhanced public access in the late 1930s resulted in improvement of the access road at the eastern end of the pond which has been maintained in one form or another since. In 2006, the Commonwealth transferred ownership of most county access roads to the towns in which they lie. However, the rights, title, and interest of the White Pond access road was not transferred and remains in ownership of the Commonwealth (MGL Ch34B § 6).

> “This pond has rarely been profaned by a boat, for there is little in it to tempt a fisherman.”
> -Henry David Thoreau

The history of the White Pond recreational fishery is rather convoluted and the pond has been variously described as hosting poor to excellent fishing opportunities. For instance, in 1911, the state Commission on Fisheries and Game sent two biologists, Calvin B. Coulter and Roy S. Corwin, to investigate ponds with regard to their potential to produce food fish pursuant to Chapter 140 of the Resolves of 1910 (Secretary of the Commonwealth of Massachusetts 1912). At that time, Coulter and Corwin remarked that White Pond was “[n]ot fished much. Not considered good.” However, Calvin B. Coulter also remarked that the pond was the “clearest water he had seen” (Massachusetts Commission on Fisheries and Game 1911).

Since then, repeated efforts to improve fishing opportunities at White Pond have created an excellent recreational trout fishery. By 1993, White Pond was identified as one of the best coldwater fishing areas in eastern Massachusetts, suitable for management as a trophy trout pond. Today, it is still stocked with trout regularly in spring and autumn by the Division of Fish and Wildlife.

History of Pond Studies at White Pond

During the 1960s, citizen concern about changes in White Pond and surrounding land resulted in the establishment of Town-sponsored committees to develop approaches for studying and managing the pond (Sprott, 1991). The Town contracted with Ecosystems, Inc. to conduct the first comprehensive water quality and ecological assessment of White Pond in 1972 (Ecosystems, Inc. 1972). A Town-sponsored volunteer water quality monitoring program was established at this time, as well. No significant problems with water quality were documented. However, the acquisition of land on the southwestern periphery of White Pond was recommended to prevent further development in the watershed. Spurred by this recommendation, the Town purchased ten acres of land in this area for conservation purposes in 1973.

Efforts to acquire the abutting 40.45-acre property to the west (then known as the Sperry Rand Corporation [Unisys] parcel) were initiated by the Town, and this parcel was eventually acquired for municipal purposes in 1992.

In the 1980s, algal blooms were observed on the pond and raised resident concerns that water quality problems were beginning to emerge (Sprott 1991). One of the blooms was sampled and found to host several types of cyanobacteria (Walker 1988). Although cyanobacteria are naturally occurring at low levels in most waters, they have the potential to produce harmful toxins under some conditions. Therefore, cyanobacteria blooms are generally considered to be undesirable. This spurred a series of Town-funded water quality and hydrogeologic studies between 1986 and 1990 (See Walker 1987 and Walker and Ploetz 1989, 1990, and 1991). These studies concluded that high levels of nutrients, primarily phosphorous, were reaching White Pond from human sources (cultural eutrophication) and could result in degradation of the pond if action was not taken. To address this problem, control or elimination of watershed phosphorus sources, such as direct surface run-off and poorly functioning septic systems was recommended. Echoing the 1972 study of White Pond, these studies also recommended land acquisition to prevent further unchecked development in the White Pond watershed. A large parcel of land owned by Unisys, Inc. (the “Sperry Rand Parcel”) was identified as a priority for acquisition and eventually acquired in 1992.

In subsequent years, volunteer water quality monitoring continued in White Pond. Additionally, management plans were developed by Town committees to guide the appropriate use of Town lands (e.g., White Pond Reservation Task Force 1992 and 2002, White Pond Advisory Committee 2002 and 2009).

Despite the number of studies completed at White Pond, the state has not conducted an assessment of designated uses (MassDEP 2014). Past water quality assessments at the state level were biased toward polluted water bodies, although the current monitoring strategy seeks to incorporate more water bodies located outside of problem areas, as required by Section 305(b) of the Clean Water Act (MassDEP 2005).

3.0 METHODS

3.1 Existing Information Review

ESS completed a primary review of files relevant to the White Pond Watershed Management Plan at the Concord DNR offices in August 2013 and through information provided by the White Pond Advisory Committee. This included past correspondence, newspaper articles, parcel deeds and survey plans, pond reports, fisheries records, and planning documents. A list of sources reviewed and a brief description of each is provided in Appendix B.

3.2 Field Program

The field program for this study was developed to cover critical data gaps in the development of an effective management plan for White Pond. Given the existing data available, the field program focused on pond bathymetry, biological assessment, water quality (in-pond, stormwater, and groundwater), and sediment quality.

A detailed Quality Assurance Project Plan (QAPP) was developed to ensure the field methods used for this study were appropriate to meeting project goals. The QAPP was reviewed by the Town, US Environmental Protection Agency, and MassDEP and approved on September 27, 2013. This document should be referred to for detailed descriptions of field methodologies (Appendix C). However, a summary of the methods and approach used to develop this watershed management plan is presented in the following sections.

Bathymetry

A bathymetric survey was completed at 166 points using a combination of sonar (for waters deeper than 3.0 meters [10 feet]) and a 10-foot sounding rod. Horizontal position was obtained using a Trimble GeoXT Differential GPS with sub-meter accuracy. Survey data were manually converted to bathymetric contours for White Pond using ArcGIS 10.2. The bathymetry survey was completed on October 1, 2013.

Biological Assessment

Observations of fish, plants, avifauna, and herpetofauna directly observed during each field visit were compiled into a species list for White Pond and its immediate environs. The list generated from this activity is not intended to represent an exhaustive inventory. Rather, it should be viewed as a representative list of species that currently inhabit the area over some portion of the year.

Water Quality

ESS collected in-pond, stormwater, and groundwater samples as part of the water quality field program at White Pond. All water quality samples requiring laboratory analysis were sent to Premier Laboratory of Dayville, Connecticut, a state-certified laboratory.

In-Pond Water Quality

In-pond water quality data were collected on three events (August 22 and September 17, 2013, and May 15, 2014). The first event was limited to field-measured parameters, including Secchi depth (clarity), temperature, dissolved oxygen, pH, turbidity and specific conductance. Field parameters were measured over a vertical profile from the surface of the pond to the bottom, typically spaced at 0.5- to 1.0-meter increments.

Water quality samples were collected from the top and bottom of the water column during the second and third events. Samples were analyzed by the laboratory for total phosphorus, dissolved phosphorus, and total nitrogen.

Stormwater

One round of stormwater sampling was completed on November 27, 2013. Sampling focused on six eroded bank areas along the western and southwestern shoreline of the pond. GKY, Inc. first-flush samplers were installed the afternoon prior to sampling and collected the next morning immediately following the primary rain event. Samplers were installed with collection ports flush with the ground surface and the sampling receptacle below grade.

Groundwater

Two rounds of groundwater seepage studies were completed, including one on October 18, 2013 and one on May 15, 2014. These reflect periods of seasonal low and high water table, respectively.

Seepage sampling events consisted of the installation of seepage meters to estimate the rate of in-seepage to and out-seepage from the pond within six shoreline areas. A littoral interstitial porewater sampler was also used to extract shallow groundwater for water

Collection of shallow groundwater with a littoral interstitial porewater sampler.

quality analysis. Extracted samples were measured in the field for temperature, pH and specific conductance and sent to the laboratory for analysis of dissolved phosphorus, ammonia and nitrate.

Sediment

Sediment grab samples were collected at three locations in White Pond with a 6-inch by 6-inch Ekman gravity dredge. The three grab samples were then homogenized and composited into one sample for analysis of total phosphorus, total nitrogen and several metals, including aluminum, calcium, iron and magnesium. Samples were collected on October 1, 2013.

Other Elements

ESS also conducted field reconnaissance of recreational uses at White Pond during each visit. The primary focus of the field reconnaissance was to observe water-dependent recreational uses (i.e., swimming, boating, and fishing). However, observations of other uses of the pond and its adjacent land were also made, as opportunities allowed.

Each Town-owned parcel was visited at least once to observe conditions related to slope erosion, terrestrial invasive species, connectivity to White Pond, and opportunities for implementation of stormwater BMPs or other uses.

3.3 Modeling

Data generated during field and desktop assessments were used to develop a hydrologic budget and nutrient load model for White Pond. Determining a pond's hydrologic budget is the first step toward modeling its nutrient load because all water being delivered to the pond carries some quantity of nutrients (even precipitation). A hydrologic budget includes water inflow into the pond, storage capacity within the pond, and water outflow from the pond.

Sources of water inflow include direct precipitation onto the pond surface, direct runoff from adjacent land, and groundwater seepage along the margins of the pond. Evapotranspiration and groundwater recharge lead to losses of water from the pond.

The hydrologic budget and subsequent nutrient model are important because nutrient levels influence water quality (e.g., clarity, algal production, etc.) within the pond. The results of the nutrient model are used to gain an understanding of how the pond is affected by the surrounding watershed and internal processes to help prioritize management efforts for water quality improvement.

Two approaches to nutrient modeling were used to address related but different aspects of this project (Table A). The first approach involved development of an in-lake model that used measured pond parameters (such as nutrient concentration) and both hydrologic and physical features of the pond (such as area, volume, and flushing rate), to infer the nutrient load. In-lake nutrient models were developed for both phosphorus and nitrogen (Appendix D). The second was development of a model that estimates nutrient loading from characteristics of the watershed (land-use-based model). The land-use-based model allows for the examination of impacts from future changes in watershed land use, such as development of currently forested parcels.

Table A. Summary of Modeling Approach

Model Approach	How it Works	Importance to this Plan
In-lake Model	Infers nutrient load from physical, hydrologic, and water quality features of the pond itself.	Provides a basic understanding of the magnitude of nutrient loading to the pond. Allows the relative magnitude of measured sources of nutrients to be placed in the context of total load to the pond.
Land-use-based Model	Estimates nutrient load from characteristics of the watershed.	Provides indication of level of impact from hypothetical future development in the watershed.

Parameters such as the mean depth (pond volume divided by pond area), flushing rate (number of times per year that the total volume of water in the pond is renewed), areal water load (volume of water entering a pond in a year divided by the pond surface area) and settling velocity (rate at which a particle drops from the water column) influence how nutrients move through the system and were each incorporated into the in-lake nutrient model (Appendix D).

The simplest in-lake nutrient models are derived from mass balance equations. While useful as a first step, mass balance models tend to underestimate nutrient loads because they do not account for natural loss processes that essentially reduce in-pond concentrations over time. Therefore, results from several different in-pond models were examined (Dillon and Rigler 1974, Oglesby and Schaffner 1978, Jones et al. 1979, Kirchner and Dillon 1975, Vollenweider 1968 and 1975, Reckhow 1977, Larsen and Mercier 1976, Bachmann 1980, and Jones and Bachmann 1976) (Appendix D). The individual model results were averaged to obtain an estimate of the phosphorus and nitrogen load entering White Pond.

Physical and hydrologic characteristics of White Pond were used to determine what are referred to as the *permissible load* and *critical load* for phosphorus (Vollenweider 1975). Calculation of permissible and critical loads depends primarily on the residence time of water in the pond and its depth and is not influenced by actual nutrient loading. Rather, these loads are approximations of a lake's assimilative capacity for nutrients based on its physical and hydrologic characteristics and are thus a framework against which to view the actual loading.

The *permissible load* represents the point above which a pond can be expected to experience regular problems with excessive algal growth and rapid deterioration of water quality. Although algal blooms can occur below the permissible load, water quality deterioration significantly accelerates above this level. Therefore, maintaining or reducing nutrient inputs to a point well below the permissible load is very important.

The *critical load* represents an upper threshold, above which a pond can be expected to experience persistent problems with excessive algal growth. Above the critical load, the rate of water quality deterioration actually slows with increased inputs because the pond is already saturated with nutrients. This represents a state of advanced eutrophication (nutrient enrichment). Water bodies above the critical load are challenging to restore because large nutrient reductions are required to achieve even minimal improvements in water quality.

The permissible and critical loads are not intended to represent a specific water quality threshold or goal for White Pond. However, they are helpful in characterizing how a pond is likely to respond to changes in nutrient loading.

Actual nutrient loading can be estimated from in-lake or land-use-based models. The simplest in-lake nutrient models are derived from mass balance equations. Mass balance equations assume that what goes into the system must come out. While useful as a first step, mass balance models tend to underestimate nutrient loads because they do not account for natural loss processes that essentially reduce in-pond concentrations over time, such as sequestration in the sediments. Therefore, results from several different in-pond models were examined (Dillon and Rigler 1974, Oglesby and Schaffner 1978, Jones et al. 1979, Kirchner and Dillon 1975, Vollenweider 1968 and 1975, Reckhow 1977, Larsen and Mercier 1976, Bachmann 1980, and Jones and Bachmann 1976) (Appendix C). The individual model results were averaged to obtain a final estimate of the phosphorus and nitrogen load entering White Pond.

These models were developed based on relationships measured in drainage lakes (i.e., lakes with significant surface inflows and outflows) and the predictive power of these models for kettle ponds like White Pond is not well-understood. However, it is appropriate to use them for comparison to other ponds and to estimate the general level of management that would be required to achieve desired water quality. Colman and Friesz (2001) used relationships established by Vollenweider in their analysis of Walden Pond because these relationships are useful for comparing the state of one pond to other water bodies. In sum, despite their limitations, the in-pond models do reliably indicate direction and approximate magnitude of change to be expected with increasing or decreasing nutrient loads (Mattson et al. 2004).The results of the in-lake modeling were used to calibrate the land-use-based nutrient export model for the White Pond watershed. Under the land-use-based approach, each land use was assigned a nutrient export coefficient based on established literature values (e.g., Reckhow 1980). For example, high density urban development generates the most nutrients per unit of land while forested areas and wetlands export the lowest levels of nutrients. The total nutrient load contributed from the watershed depends on the acreage of each land use and the nature of the route that runoff from the drainage area must travel to reach the pond. An attenuation factor was used in the development of this land-use-based model to account for the fact that a portion of the nutrients generated in the watershed does not reach the pond. Watersheds with few direct pathways for mobilization of nutrients have lower attenuation factors, while those with many direct pathways (such as stormwater drains and roads) have higher attenuation factors.

More details on the modeling approach used for this study are presented with the modeling results in Section 4.

4.0 RESULTS

4.1 Field Program Results

Quality Assurance/Quality Control

No significant deviations from the QAPP occurred and all project-specific QA/QC criteria were met with regard to precision, accuracy and completeness of the data collected. Therefore, the dataset used to develop this watershed management plan is believed to be of sufficient quality to achieve project goals.

Bathymetry

White Pond is characterized by three deep central basins, each reaching a depth of 15 meters (50 feet) or more. These basins are divided by intervening shallow zones (Figure 2). Water depths drop off quickly over most of the pond, with the exception of the White Pond Associates, Inc. beach and sheltered coves, including Sachem's Cove. The deepest point recorded during the bathymetry survey in White Pond was 59 feet.

Biological Assessment

Algae and Macrophytes

Primary productivity in White Pond appears to be predominantly algae driven. In particular, planktonic algae (phytoplankton) form a distinct lens near the thermocline in the late spring and summer. Although prior observations by pond residents and visitors provide anecdotal evidence of this lens possibly rising to the surface and forming a mat or scum, this phenomenon was not observed during the current study. Patches of filamentous green algae (Chlorophyceae) were observed growing on coarse detritus in sheltered shoreline areas.

Golden hedge-hyssop is common along the shoreline of White Pond.

Aquatic macrophytes in White Pond were restricted almost entirely to narrow strips along shallow shoreline areas. In these areas, only two low-growing native taxa, including spikerush (*Eleocharis* sp.) and golden hedge-hyssop (*Gratiola aurea*) were encountered. Although these taxa can locally form dense mats of growth, neither is considered to be problematic from an ecological or recreational point of view. Small emergent patches of plant growth were present along the shoreline, primarily in Sachem's Cove, but continuous stands of larger emergents, such as the blue flag iris noted by Thoreau, were not present.

> [T]he blue flag (*Iris versicolor*) grows thinly in the pure water, rising from the stony bottom all around the shore…"
> -Henry David Thoreau

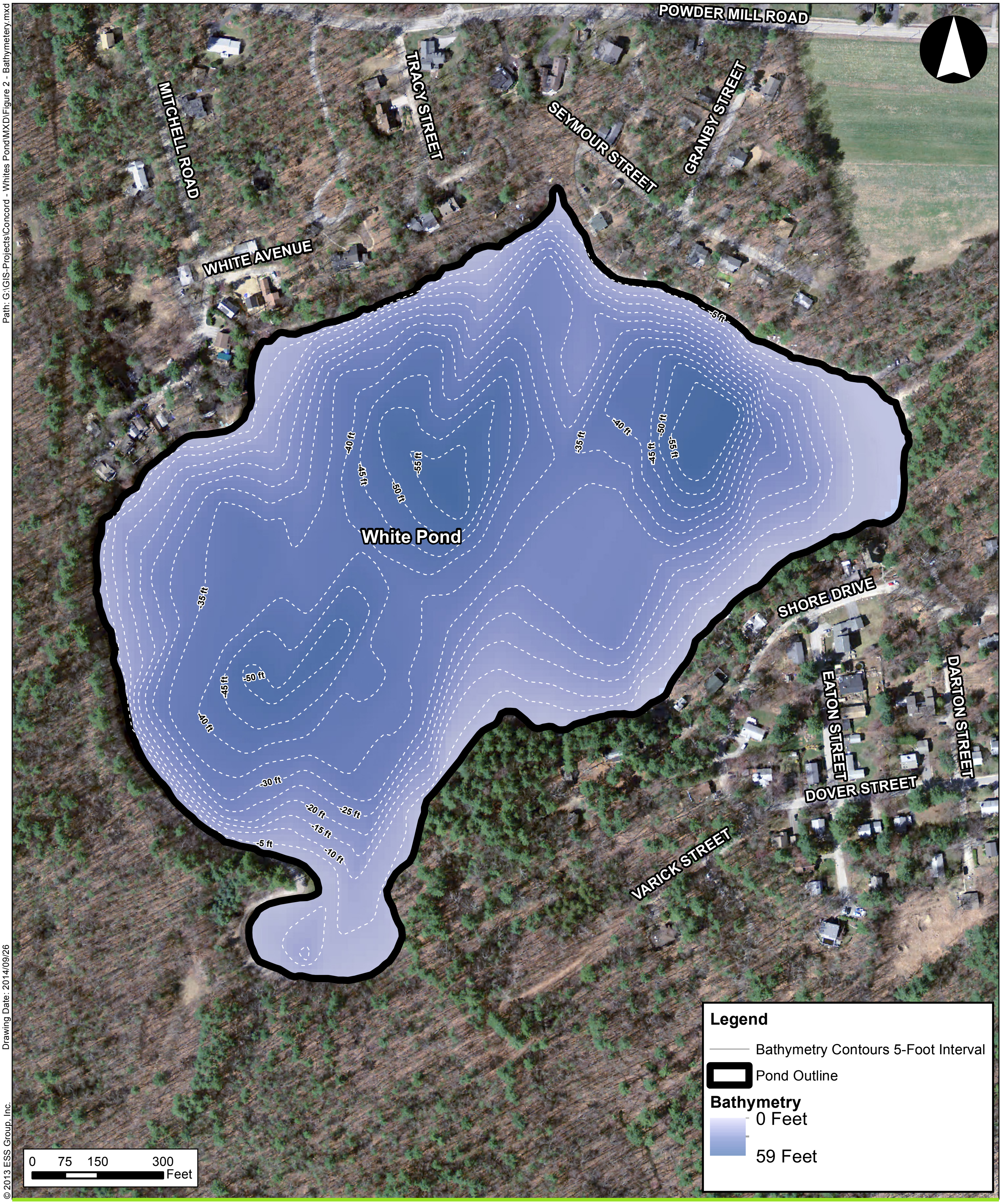
Although not explicitly encountered during our survey work, two rare plants are associated with Priority Habitat designated by the Massachusetts Natural Heritage and Endangered Species Program as occurring in and adjacent to White Pond. Based on information obtained through the BioMap2 Town Report for Concord (NHESP 2012), it is likely that these species include Engelmann's umbrella sedge (*Cyperus engelmannii*) and resupinate bladderwort (*Utricularia resupinata*). Both of these species prefer sandy habitat along pond margins.

No exotic invasive macrophyte species were encountered in White Pond. Given White Pond's sandy to gravelly open shorelines and steep bathymetry, it is not likely to be overtaken by large contiguous beds of invasive plants. However, there are a few invasive species that specialize in the nutrient-poor shoreline habitats and deeper waters characteristic of White Pond and every effort should be made to ensure that these and other invasive species are not introduced into the White Pond ecosystem.

Primary among these is mudmat (*Glossostigma cleistanthes*), an Australian plant of small stature that creates a green carpet in shallow, sandy to gravelly habitats, potentially displacing desirable native plants. Since the early 2000s, mudmat has spread into multiple water bodies across Connecticut and Rhode Island as well as Worcester County, Massachusetts (Les et al. 2006, Cullina et al. 2011).

Path: G:\GIS-Projects\Concord - Whites Pond\MXD\Figure 2 - Bathymetery.mxd

Drawing Date: 2014/09/26



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White Pond
Concord, Middlesex County, Massachusetts

1 inch = 300 feet

Source: 1) USGS, Aerial Imagery 0.3m, 2013
2) ESS Bathymetry, 10/1/2013

White Pond Bathymetry
Based on October 1, 2013 Survey

Figure 2

Additionally, an invasive European macroalga called starry stonewort (*Nitellopsis obtusa*) poses a potential threat to nutrient-poor shallows and deepwater habitat. Although it was originally documented in North America in 1978, it did not begin to spread in earnest to inland lakes until the 2000s (Kipp et al., 2014). It is now documented in multiple inland lakes in the Great Lakes region as well as the Finger Lakes in New York. In some of these lakes, it has become the most aggressive invasive species, even displacing other highly invasive species such as fanwort (*Cabomba caroliniana*).

Fish

Coldwater fish habitat currently comprises about 16 percent of the total volume of White Pond during the late summer months, when it is restricted to oxygen-rich areas at or below the thermocline. Warmwater fish habitat is dominated by open water over sand or gravel bottom. Cover is limited to occasional submerged logs or boulders, smaller organic debris, and manmade features such as docks, swimming platforms, and moorings. Aquatic macrophyte growth provides minimal additional cover, primarily for small or young-of-the-year fish.

Golden shiner (*Notemigonus crysoleucas*) rainbow trout (*Onchorynchus mykiss*), brown trout (*Salmo trutta*), largemouth bass (*Micropterus salmoides*), and sunfish (*Lepomis* spp.) were directly observed by ESS at White Pond over the course of multiple field visits (Table B). Prior data from multiple Massachusetts Division of Fisheries and Wildlife surveys suggest a more species-rich fish community that includes several warm and coldwater species.

Table B. Fish Observed at White Pond, 1911 to Present*

Common Name	Scientific Name	Year							
		1911	1953	1954	1955	1958	1982	1993	2013/14
Atlantic Salmon	*Salmo salar*								S
Black Crappie	*Pomoxis nigromaculatus*		X						
Bluegill	*Lepomis macrochirus*							X	X
Brook Trout	*Salvelinus fontinalis*			X	C	C	C	X	
Brown Bullhead	*Ameirus nebulosus*		X			R	R		
Brown Trout	*Salmo trutta*		C			C	R		X
Chain Pickerel	*Esox niger*		X					X	
Creek Chubsucker	*Emyzon oblongus*						R		
Golden Shiner	*Notemigonus crysoleucas*	X	X		D	C	C	X	X
Largemouth Bass	*Micropterus salmoides*		X			R		X	X
Pumpkinseed	*Lepomis gibbosus*	X	X			C	C	X	X
Rainbow Trout	*Oncorhynchus mykiss*		C	C-R	R	C	R	X	X
Rock Bass	*Ambloplites rupestris*						R		
Smallmouth Bass	*Micropterus dolomieu*						R	X	
Yellow Perch	*Perca flavescens*		D						

D=dominant, C=common, R=rare, X=present (no abundance data available), S=not observed but known to have been stocked
*All data Massachusetts Division of Fisheries and Wildlife , except 2013/14 collected explicitly for this plan

Table C. Other Wildlife Observed at White Pond during the Current Study*

Group	Common Name	Scientific Name	2013				2014
			8/22	9/17	10/1	11/27	5/15
Avifauna	American Crow	*Corvus brachyrhynchos*			✓	✓	✓
	American Robin	*Turdus migratorius*					✓
	Bald Eagle (non-breeding)	*Haliaeetus leucocephalus*				✓	
	Baltimore Oriole	*Icterus galbula*					✓
	Barn Swallow	*Hirundo rustica*	✓				
	Belted Kingfisher	*Megaceryle alcyon*	✓			✓	✓
	Black-capped Chickadee	*Poecile atricapillus*	✓		✓	✓	✓
	Black-throated Green Warbler (non-breeding)	*Dendroica virens*					✓
	Canada Goose	*Branta canadensis*				✓	
	Chimney Swift	*Chaetura pelagica*	✓				
	Chipping Sparrow	*Spizella passerina*					✓
	Eastern Kingbird	*Tyrannus tyrannus*					✓
	Eastern Phoebe	*Sayornis phoebe*					✓
	Great Blue Heron	*Ardea herodias*					✓
	Herring Gull (non-breeding)	*Larus argentatus*				✓	
	Mallard	*Anas platyrhynchos*				✓	✓
	Osprey	*Pandion haliaetus*					✓
	Red-tailed Hawk	*Buteo jamaicensis*					✓
	Ring-billed Gull (non-breeding)	*Larus delawarensis*				✓	
	Spotted Sandpiper	*Actitis macularius*					✓
	Tufted Titmouse	*Baeolophus bicolor*			✓		✓
	White-breasted Nuthatch	*Sitta carolinensis*		✓	✓		✓
	Yellow Warbler	*Dendroica petechia*					✓
Herpetofauna	Green Frog	*Rana clamitans*					✓
	Wood Frog	*Rana sylvatica*					✓
	Painted Turtle	*Chrysemys picta*	✓	✓			

*This list reflects a limited number of observations and is intended to be representative of species that would commonly occur at White Pond during the appropriate season. It is not intended to be used an exhaustive checklist of species known or likely to occur at the pond.

Other Species

A number of other avian and herpetofauna species were directly observed by ESS using the pond or immediate shoreline areas (Table C). Most of these are regionally common woodland and pond species.

The only state-listed species observed was an adult Bald Eagle. However, this observation was a solitary individual in the late autumn. White Pond and its watershed do not appear to be used as a winter roosting or breeding site for Bald Eagle.

Although not directly observed, mammals such as white-tailed deer, coyote, red fox, gray squirrel, eastern chipmunk, raccoon, and striped skunk are expected to be found in the watershed.

Invasive Plants in the Watershed

Reconnaissance of upland portions of the watershed over multiple visits generated a modest number of exotic plant species, most of which are common regionally (Table D). This list focuses primarily on woody species. Additional herbaceous species, including woodland invasives such as garlic mustard (*Alliaria petiolata*), are likely to be present in the watershed.

Table D. Invasive Plant Species Observed in the White Pond Watershed

Common Name	Scientific Name	Abundance	Areas Observed
Autumn Olive	*Eleagnus umbellata*	Common	Borders of agricultural lands and roadsides
Japanese Barberry	*Berberis thunbergii*	Occasional	Understory of disturbed woodland edges
Multiflora Rose	*Rosa multiflora*	Common	Borders of agricultural lands and roadsides
Norway Maple	*Acer platanoides*	Common	Along public access road and disturbed woodland edges
Oriental Bittersweet	*Celastrus orbiculatus*	Common	Along public access road and disturbed woodland edges

*This list reflects a limited number of observations and is intended to be representative of invasive species that occur in the White Pond watershed. It is not intended to be used an exhaustive checklist of species known to occur in the watershed.

Water Quality

In-Pond Water Quality

With an average depth of 27 feet, White Pond is of sufficient depth to stratify completely during the summer and winter. In the summer, a warm, well-mixed layer of water develops at the top (epilimnion) of the pond above a cooler layer at the bottom (hypolimnion). This temperature inversion effectively separates the two layers so that they do not physically mix with each other and become effectively separated over the summer.

Dissolved oxygen appears to be plentiful most of the year in the epilimnion, although hypoxic or anoxic conditions may occur in the lower portion of the hypolimnion from late spring into autumn. In White Pond, an algal lens develops near the interface between the epiliminion and hypolimnion. The photosynthesis of these algae during the day creates supersaturated (i.e., in excess of 100 percent of the amount of oxygen the water can hold) dissolved oxygen conditions within a narrow band of water (Figure 3). Although the dissolved oxygen and temperature profiles from September 17, 2013 were truncated, they are sufficiently deep to show a thermal inversion and hypolimnetic oxygen depletion.

White Pond may be generally characterized as being of circumneutral pH and possessing high water clarity with low levels of dissolved salts and low concentrations of macronutrients (i.e., nitrogen and phosphorus).

More specifically, pH in the surface waters of White Pond varies from slightly acidic to somewhat alkaline depending on the time of day and weather conditions. This phenomenon is typically observed in relation to diurnal photosynthetic activity, which tends to temporarily raise pH by removing dissolved carbon dioxide (carbonic acid) from water.

Specific conductance, an indirect measurement of dissolved salts, was observed to range between 52 and 79 µS/cm. These levels are typical of minimally to slightly impacted soft waters in southern New England. Road salts, septic effluent, and lawn and garden runoff (containing fertilizer, lime and other soil conditioners) can all raise the specific conductance of the water.

Water clarity, as measured by Secchi depth varied from 5.25 m to 6.75 m between sampling events. Likewise, surface turbidity was below 1.0 NTU. Water clarity results obtained as part of this study were within the range of values observed from 1987 to 2013 (Walker 2014).

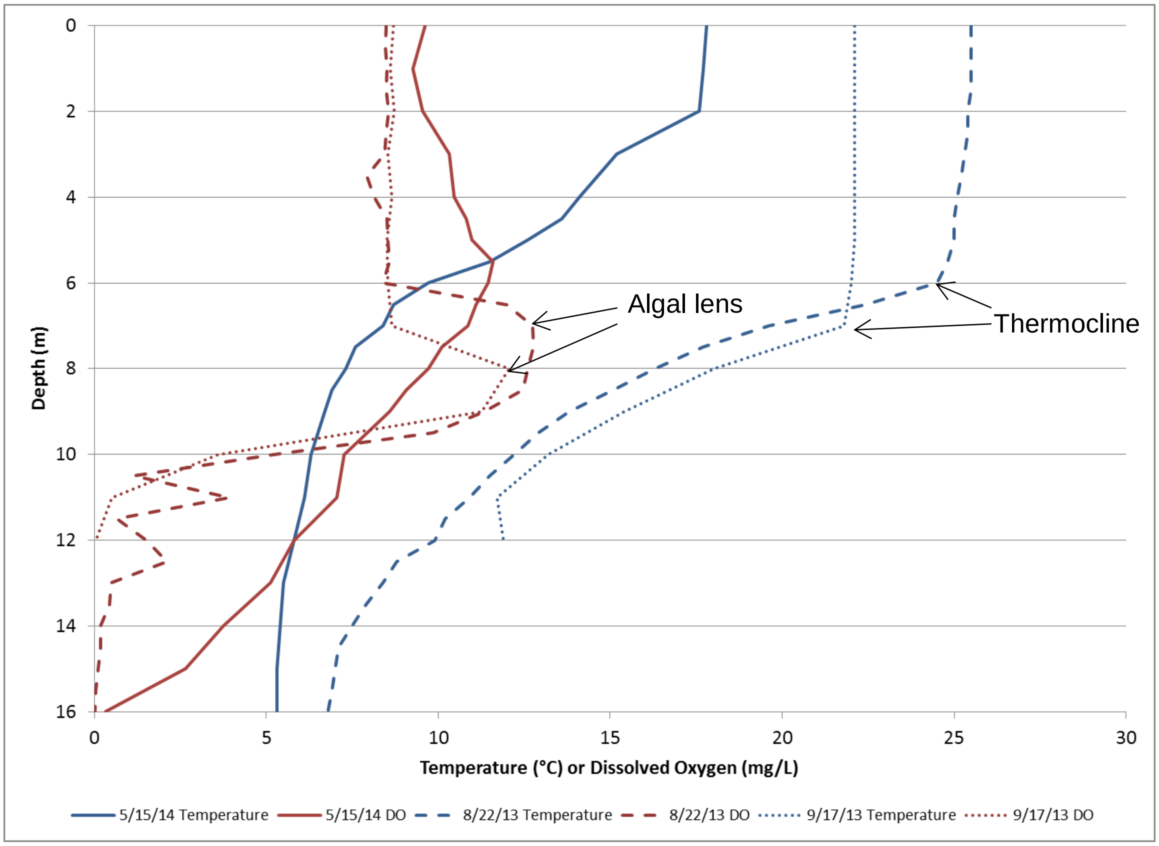

Figure 3. White Pond Temperature and Dissolved Oxygen Profiles

Carlson (1977) developed a Trophic State Index (TSI) to standardize facilitate communication with the public regarding the trophic status of lakes. The TSI scale was first derived for Secchi disk transparency but additional parameters, such as total phosphorus and chlorophyll *a* were also incorporated. In practice, the TSI scale extends from 0 (nutrient-poor) to 100 (extremely fertile) and provides greater potential discrimination in trophic status than the three traditional trophic categories (oligotrophic, mesotrophic, and eutrophic). However, the scale was designed to also correspond to the coarser traditional categories, as follows: oligotrophic ponds less than 40, mesotrophic ponds between 40 and 50, and eutrophic ponds above 50. The measured values for water clarity and total phosphorus at White Pond were transformed into TSI scores to facilitate discussion of its trophic state.

The water clarity values collected as part of this study are considered to be very good to excellent and typical of an oligotrophic pond (Table E). However, Walker and Ploetz (1988) cautioned against classifying White Pond as an oligotrophic water body based on water clarity alone because algae tend to concentrate deep in the thermocline of the pond.

Phosphorus levels in White Pond were low to very low (close to 0.01 mg/L), except at the bottom of the pond in May. The elevated total phosphorus at this time may stem from physical disturbance of bottom sediments by currents. This is reflected in the turbidity, which was over 2 NTU at the time. The resuspension of sediments in the bottom of the water column could temporarily carry phosphorus that is adsorbed onto sediment particles or complexed with metals such as iron or aluminum. Higher levels of dissolved phosphorus at the bottom of the pond in May could be related to limited chemical release of phosphorus from anoxic bottom sediments.

Total phosphorus results obtained as part of this study were characteristic of an oligotrophic to mesotrophic pond (Table E). Concentrations were lower than those observed in the 1980s but higher than those observed in the early 1970s (Walker and Ploetz 1988). These changes may reflect the increase in anthropogenic pressures from the 1970s to the 1980s (worsening conditions), followed by significant septic system upgrades, installation of the catch basins and infiltration system at the public access road, and stabilization of failing slopes (improving conditions). However, interfering factors, such as different distributions of samples through the water column and changes in laboratory analytical methods make direct comparisons of phosphorus levels across the years less certain than those for water clarity (Secchi depth).

The TSI scores for total phosphorus were consistently higher than those associated with Secchi depth but not drastically so. In general, they indicate White Pond is likely to be a water body on the upper end of the oligotrophic classification. This is further supported by other characteristics of the pond, including the sparse growth of aquatic plants and the presence of a holdover trout fishery despite development of some seasonal anoxia in the hypolimnion (Carlson and Simpson 1996).

Table E. Trophic State of White Pond Based on Phosphorus and Secchi Transparency

Metric	Total Phosphorus	Secchi Transparency
Observed Range in Values	<0.010 mg/L to 0.014 mg/L*	5.25 m to 6.75 m
Trophic State Index Range	37 to 42	32 to 36
Trophic State Classification Range	Oligotrophic to Mesotrophic	Oligotrophic

*0.039 mg/L observed on May 15, 2014 but likely to be influenced by resuspension of sediments

Nitrogen levels were low to moderate (less than 1.0 mg/L) in both the surface and bottom waters of White Pond. Total Kjeldahl nitrogen (TKN), which includes dissolved ammonia as well as organic nitrogen, was highest at the bottom of the pond in May. As with phosphorus, this somewhat higher value of TKN is likely related to brief resuspension of sediments induced by bottom currents and does not necessarily indicate degradation of water quality in the pond.
Details of surface and bottom in-pond water quality are presented in Table F.

Table F. In-pond Water Quality Summary

Date	Depth (m)	Temp (˚C)	Dissolved (mg/L)	Oxygen (% Sat)	pH (SU)	Specific Conductance (µS/cm)	Turbidity (NTU)	Secchi Depth (m)	Total Phosphorus (mg/L)	Dissolved Phosphorus (mg/L)	TKN (mg/L)	Nitrate (mg/L)
8/22/2013	Surface	25.5	8.49	103.5	6.9	65	NS	5.25	NS	NS	NS	NS
	Bottom	6.8	0.02	0.2	NS	79	NS	NA	NS	NS	NS	NS
9/17/2013	Surface	22.1	8.7	98.3	8.02	62	0.39	6.20	*0.010*	*0.010*	*0.500*	*0.050*
	Bottom	11.9	0.05	0.6	6.85	52	0.65	NA	0.014	*0.010*	*0.500*	*0.050*
5/15/2014	Surface	17.8	9.62	100.8	7.41	63	0.78	6.75	0.012	*0.010*	*0.500*	*0.050*
	Bottom	5.3	0.33	2.3	6.94	67	2.27	NA	0.039	0.013	0.84	*0.050*
Numerical State Standard		NA	6.0	60%	6.5 to 8.3	NA	NA	NA	NA	NA	NA	NA
Other Standards		NA	NA	NA	NA	NA	3.04**	4.50*	0.008*	NA	0.32* (Total Nitrogen)	

Italics indicate analyte was not detected at the laboratory quantitation limit
NS=Not sampled (ESS elected to collect an additional round of water quality data for *in situ* parameters only)
NA=Not applicable
*US EPA 2014 for Lakes and Ponds - these represent *recommended* criteria
**US EPA 2014 for Streams and Rivers (where standard for lakes and ponds is absent) - these represent *recommended* criteria

Stormwater

Stormwater collected as sheet or rill flow from eroded shoreline areas contained excessive concentrations of total suspended solids (TSS), total nitrogen and total phosphorus (Table G, Figure 4). However, specific conductance was generally similar to background levels measured in White Pond, indicating minimal levels of dissolved salts. Total phosphorus was also excessive in stormwater overflowing the catch basin at the base of the public access road. However, TSS and total nitrogen, though still high, were much reduced compared to the concentrations measured from the eroded shoreline slopes (Table G, Figure 4).

Installation of the stormwater sampler on November 26 (left) and recovery of the sampler on November 27 (right), following an overnight storm of 1.74 inches. Note the evidence of significant soil mobilization by flowing water in the photo to the right.

As with the other water quality data collected as part of this study, the concentrations reported here have limited use outside the context of both watershed hydrology and the in-pond processes that affect availability and fate of each pollutant. The significance of these stormwater water quality results is discussed in Section 4.4.

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Drawing Date: 3/10/2015

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White Pond

Concord, Middlesex County, Massachusetts

0 37.5 75 150 Feet

1 inch = 150 feet

Source: 1) USGS, Aerial Imagery 0.3m, 2013
2) Town of Concord, Parcels, 2010

Total Area of Shoreline Erosion = 404.66 square meters

Legend

- Watershed Boundary
- Primary Shoreline Erosion Areas (Area in Square Meters)
- Parcel Boundary
- Town Conservation Land
- White Pond Reservation

Eroded Areas adjacent to Shoreline of White Pond

Figure 4
Sheet 1

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Drawing Date: 4/17/2015

ess group
environmental consulting & engineering services

White Pond

Concord, Middlesex County, Massachusetts

0 15 30 60 Feet

1 inch = 75 feet

Source: 1) USGS, Aerial Imagery 0.3m, 2013
2) Town of Concord, Parcel Data, 2010

Total Area of Shoreline Erosion = 59.34 square meters

Eroded Areas adjacent to Shoreline of White Pond

Figure 4
Sheet 2

Table G. Stormwater Quality Summary*

Area*	Parcel ID #	Owner Type	TSS (mg/L)	Specific Conductance (µS/cm)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)
Eroded Area 1	3416-1	Town	180	54	3.54	0.68
Eroded Area 2	3416-1	Town	NS	NS	NS	NS
Eroded Area 3	3412-1/ 3416-1	Town	92	63	3.05	0.66
Eroded Area 4	3412-1	Town	NS	NS	NS	NS
Eroded Area 5	3412-1	Town	310	57	5.875	0.73
Eroded Area 6	3416-1	Town	290	51	4.86	1.4
Eroded Area 7	5661	Private (Common Land)	420	37	3.793	1.6
Eroded Area 8	5708	Private	NS	NS	NS	NS
Eroded Area 9	5708	Private	100	99	11.1	0.79
Eroded Area 10	5708	Private	NS	NS	NS	NS
Catch Basin at Base of Public Access Road	3270	State	7.5	32	0.967	0.81

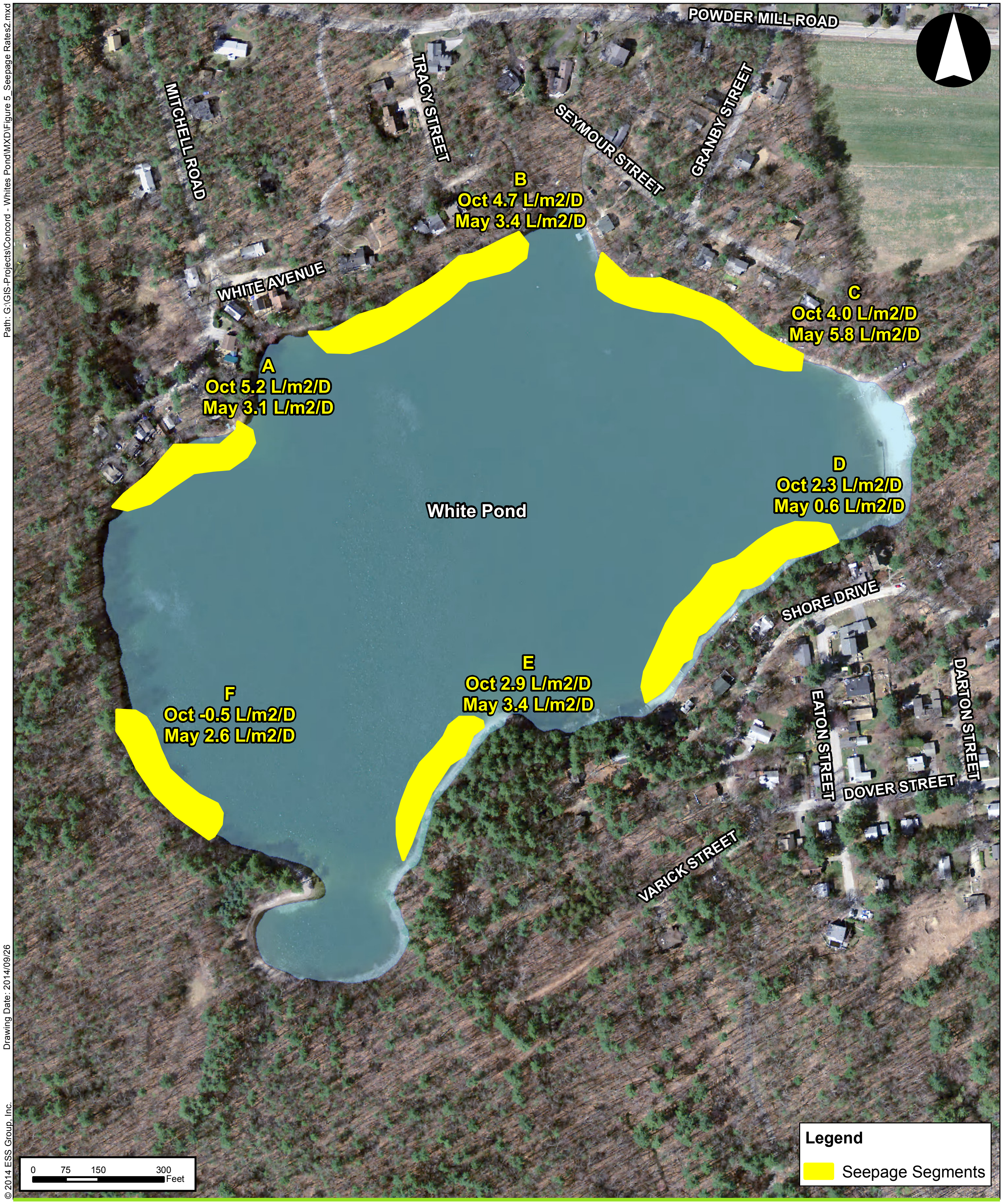
NS = Not sampled as part of this study (scope of water quality sampling was limited to six representative eroded areas)

*Refer to Section 4.4 for the implications of these results

Groundwater

Groundwater Flow Direction and Rate

During both seepage surveys, seepage of groundwater was predominantly positive (i.e., into the pond). The only exception was on the southwestern shoreline at Segment F, where seepage was slightly negative during the fall sampling event (Table H). In fall, seepage rates were highest along the northwestern shoreline of the pond (Seepage Segment A), with decreasing rates to the east and south (Figure 5). In spring, seepage rates were highest on the northeastern shoreline of the pond, with decreasing inflows to the west and south. The overall average seepage rate at White Pond was identical between fall and spring measurements.



ESS group
environmental consulting & engineering services

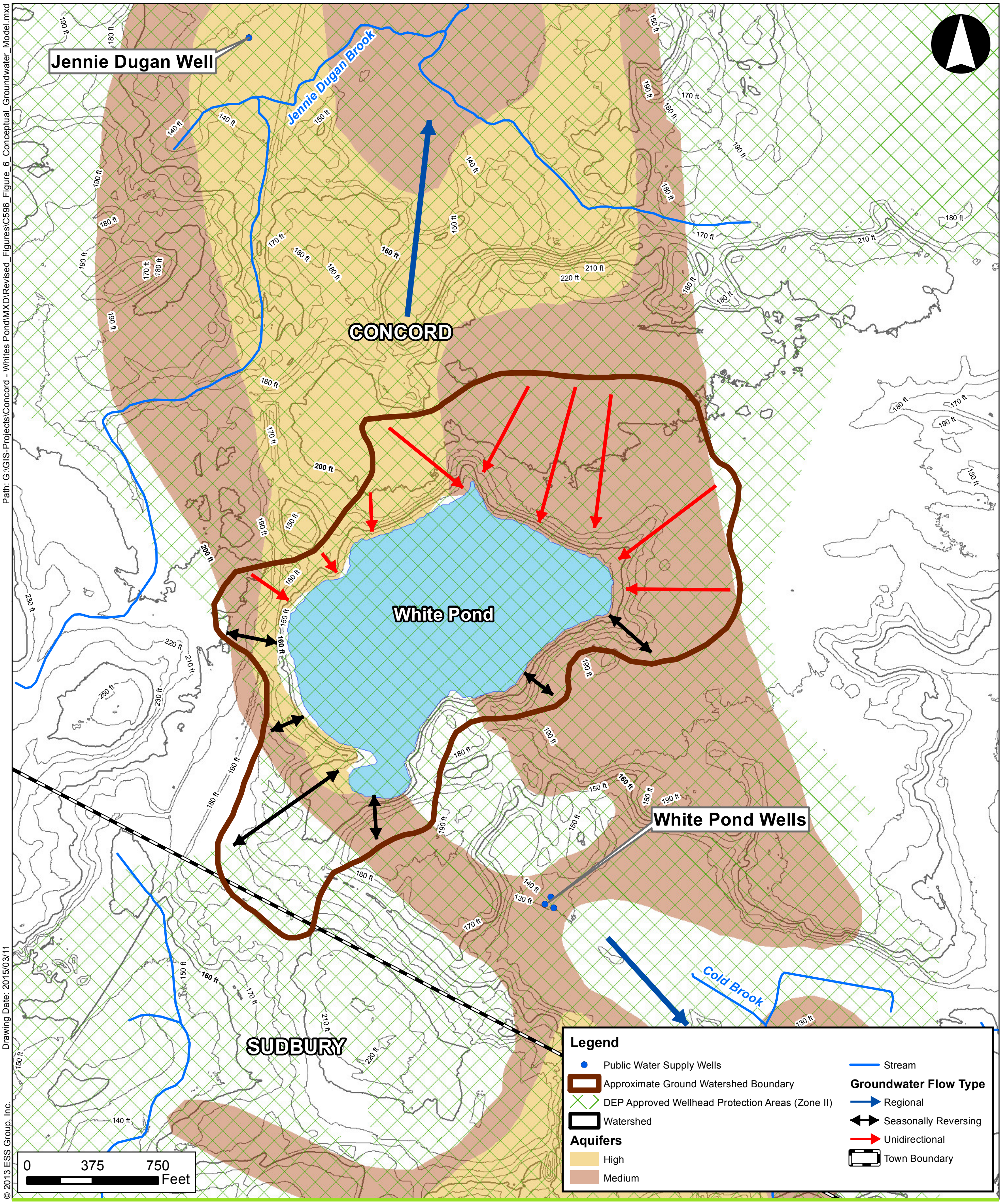
White Pond
Concord, Massachusetts

1 inch = 300 feet

Source: 1) USGS, Aerial Imagery 0.3m, 2013

White Pond Groundwater Seepage Rates

Figure 5



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& engineering services

White Pond
Concord, Middlesex County, Massachusetts

1 inch = 750 feet

Source: 1) MassGIS, LIDAR, 2010
2) MassGIS, Water Supply Wells and Aquifers, 2013
3) MassGIS - Hydrography, Town Boundaries, 2010, 2014

Conceptual Model of Regional Groundwater Flow

Figure 6

Table H. Measured Groundwater Seepage Rates

Segment	Average Seepage Rate ($L/m^2/D$) October 1, 2013	Average Seepage Rate ($L/m^2/D$) May 13, 2014
A	5.2	3.1
B	4.7	3.4
C	4.0	5.8
D	2.3	0.6
E	2.9	3.4
F	-0.5	2.6
Overall Average	3.1	3.1

The results of the groundwater seepage surveys on October 1, 2013 and May 13, 2014 generally concurred with the findings of previous work by Walker and Ploetz (1990) in that the potential for groundwater outflow from the pond was evident in the southwest area of the pond.

Considering these results in the context of the regional hydrogeologic setting a conceptual model of groundwater flow conditions in the vicinity of the pond was developed (Figure 6).

White Pond and its associated surface watershed are located within stratified drift deposits trending north to south that contain large contiguous areas of unconfined aquifers. Regional groundwater flow in the vicinity of White Pond is expected to be focused within the more permeable stratified drift deposits both northerly towards Jennie Dugan Brook and southerly towards Cold Brook (Figure 6). Both brooks eventually discharge to the Sudbury River, which is located approximately 1.5 miles to the east of White Pond.

With the exception of the southwestern portion of the watershed and a small area just to the south of White Pond, most areas are classified as high- and medium-yield aquifers. The White Pond watershed is mostly located within the Zone II Wellhead Protection Area of the Town wells, except for two small areas at the extreme western end of the watershed (Figure 6).

Nearby municipal water supply wells are located to the south (White Pond Well) and north of the pond (Jennie Dugan Well) to exploit the ready supply of water contained in these aquifers. Although these wells are considered to be outside the White Pond watershed, it is still possible that groundwater flow conditions in the vicinity of the pond could be influenced by municipal well operation. The White Pond Well, in particular, is very close to the pond, at a distance of just over 1,000 feet.

Walker and Ploetz (1989 and 1990) observed variability in the direction of groundwater flows adjacent to White Pond. They attributed this to dryer weather at times (e.g., 1988) but also potentially to the operation of the White Pond municipal wells, whose cone of influence was mapped by IEP, Inc. (1979) as extending into the southern portion of White Pond.

Walker and Ploetz (1989) observed water levels two to three feet below 1987 levels during the summer of 1988. They attributed this to the dryer weather in 1988 as well as the increased volume of water pumped at the Town well to the south. However, Walker (2014) demonstrated that historical water levels at White Pond have varied as much as 1.5 meters (5.0 feet) and were associated with lagged precipitation trends. The multiple-year lag observed is related to the time it takes for groundwater to move through watershed soils and into the pond.

To further examine the relationship, if any, between pumping at the Town well, groundwater flow direction and in-pond water levels, groundwater pumping records for the period from 1996 to 2013 were obtained from the Water and Sewer Division. Patterns in annual pumping volumes were compared with watershed precipitation (based on records from Hanscom Field in Bedford). Water losses due to evapotranspiration rates for the region were accounted for using average annual evapotranspiration data available for the region (NRCC 2014). Median annual water level in White Pond (measured by volunteers at the "Sprott" location [WhitePond.org 2014]) was also examined. Collectively, these data were available for the 1999 to 2013 period.

Using these data, a simple comparison of representative annual values for watershed precipitation (less evapotranspiration), pumping volume at the White Pond wells, and water level in White Pond itself was developed. When plotted with annual precipitation and median annual water level in White Pond, the White Pond wells groundwater pumping records for the period from 1996 to 2013 show a general pattern of increased pumping during dry years and reduced withdrawals during wet years, at least for the first half of the record (Figure 7). Water levels in the pond show a similar pattern, although there is some evidence of lagged responses between the different elements in the system.

In 2007 the Town activated a new water treatment facility located at the Deaconess well site. This treatment facility was designed to treat water withdrawn from both the Deaconess well and the White Pond Well. Following the successful installation of his facility, the Town was able to utilize the White Pond well as originally planned - year round and in keeping with its authorized withdrawal capacity. Precipitation decreased over most of the same period, with low annual totals in 2012 and 2013. Meanwhile, despite the increased pumping rates, pond water levels actually reached their peak levels in 2010, when the highest water levels in at least 15 years were observed at White Pond. These water levels coincided with record March rainfall across much of southern New England. Many locations in eastern Massachusetts recorded 15 inches or more in one month (Grumm 2011). More importantly, this event occurred immediately following an extended wet period, in which annual precipitation was above average nearly every year from 2002 to 2009, except for 2007. Therefore, pond levels were already high prior to 2010 (Figure 7).

In 2010, nearby Walden Pond also attracted media attention for very high water levels that inundated its sandy beaches (Lefferts 2010). Since then, Walden Pond's water levels have dropped substantially (Walker 2014), as have White Pond's (Figure 7). This does not necessarily suggest that Walden Pond and White Pond are supplied by the same groundwater source; as kettle ponds in the same municipality, it is not surprising that Walden Pond and White Pond display a similar response in water levels. However, it does demonstrate that White Pond is not unique in experiencing a decline in water levels since 2010.

> "[White Pond] is a lesser twin of Walden. They are so much alike that you would say they must be connected under ground."
> -Henry David Thoreau

Even with the observed decline in pond water level, 2013 water levels were still higher than during the very low water years of 2002 and 2003, when antecedent precipitation was low and pumping rates were much lower. The fact that water levels in White Pond did not drop below the 2002 levels despite much greater groundwater pumping rates and two years of below-average precipitation would appear to indicate that pumping of the White Pond wells is not a primary cause for the current drop in water levels.

Groundwater Quality

Groundwater quality results indicated no excessive levels of soluble (dissolved) phosphorus (Table I). In fact, phosphorus was not detectable in any of the samples collected. This suggests that problems with failing or inadequate septic systems were not severe or widespread enough to influence the quality of the groundwater reaching the pond. Septic systems that function correctly should have a minimal or undetectable dissolved phosphorus signature because the fraction of phosphorus leached into the ground readily adsorbs onto particles in the soil matrix, rather than migrating toward the pond.

Soluble inorganic nitrogen, or SIN (ammonia- and nitrate-nitrogen) is much more mobile through soil than phosphorus and may therefore generate a plume that reaches the pond quickly. Even septic systems that are regularly pumped and functioning properly typically remove just 25 to 35 percent of total nitrogen. Therefore, SIN concentrations in groundwater can be orders of magnitude higher where septic systems are prevalent. At White Pond, groundwater levels of SIN were moderate overall with the highest concentrations detected at segment D (southeastern shoreline of the pond) during each visit (Table I). SIN concentrations were consistently higher in autumn than in spring, possibly due to greater dilution in spring from higher water tables.

However, as with the other water quality data collected as part of this study, the concentrations reported here have limited use outside the context of both watershed hydrology and the in-pond processes that affect availability and fate of each pollutant (Section 4.4).

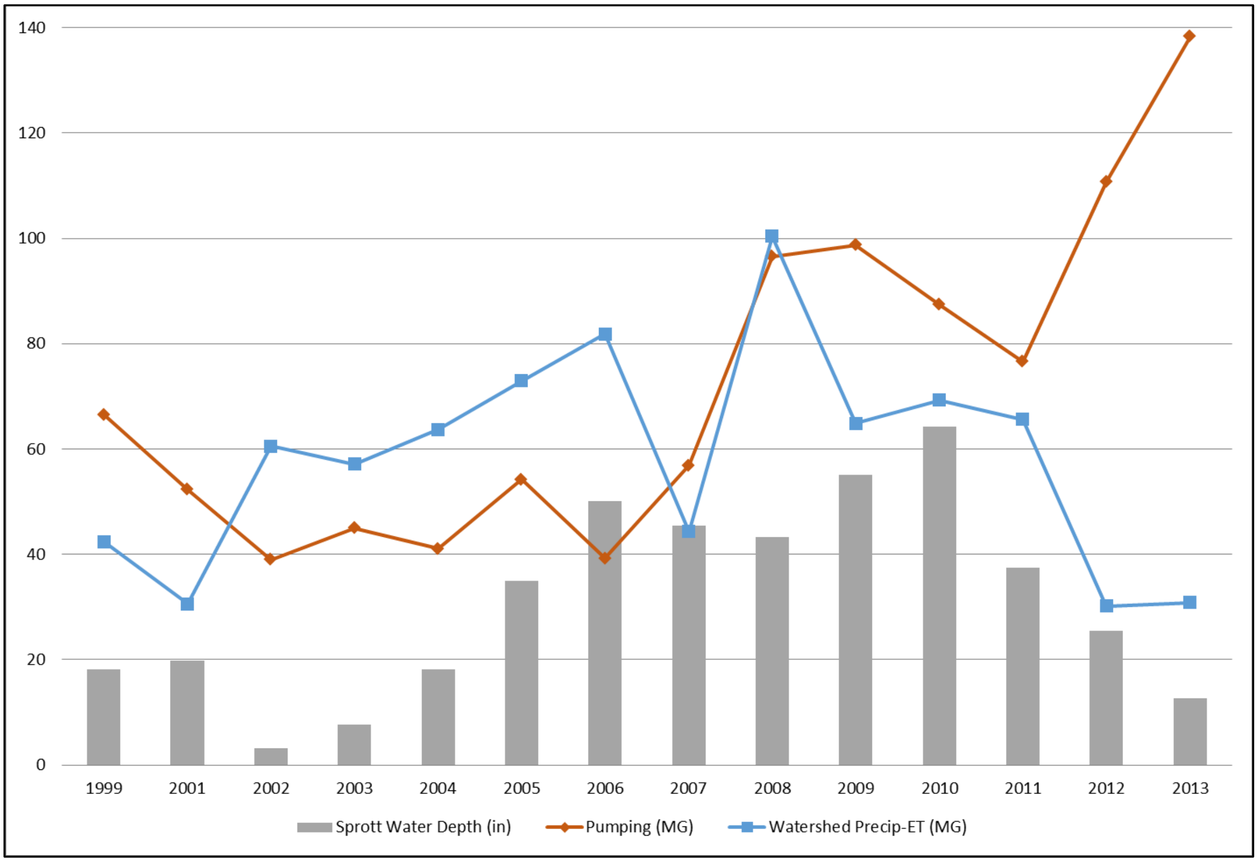


Figure 7. White Pond Wells Pump Rate Compared to Watershed Precipitation and Water Level, 1999-2013

Table I. Groundwater Quality Summary

Date	Segment	Dissolved Phosphorus (mg/L)	SIN (mg/L)
10/1/2013	A	*0.010*	0.61
	B	*0.010*	0.42
	C	*0.010*	0.82
	D	*0.010*	1.17
	E	*0.010*	0.63
	F	*0.010*	1.00
5/13/2014	A	*0.010*	0.24
	B	*0.010*	0.42
	C	*0.010*	0.71
	D	*0.010*	0.83
	E	*0.010*	0.48
	F	*0.010*	0.66

Italics indicate analyte was not detected at the laboratory quantitation limit

Sediment Quality

Sediment quality results indicate that nitrogen and phosphorus are both present at detectable concentrations (Table J). There are no applicable state standards for nutrients or aluminum, calcium, iron, and magnesium in sediment. However, neither nitrogen nor phosphorus is present at levels that are atypically high for pond sediments in southern New England. For example, sediments from multiple oligotrophic and eutrophic water bodies in southern New England were found to contain total phosphorus concentrations ranging from just over 200 mg/kg, to more than 1,000 mg/kg while total nitrogen in the same ponds ranged from 3,500 mg/kg to over 6,000 mg/kg (ESS unpublished data).

The ratio of the analyzed metals to phosphorus was more than 35 to 1. Iron alone was greater than 16 to 1. Typically, ratios of 16 to 1 are sufficient to sequester phosphorus in the sediments under aerobic conditions. Under anaerobic conditions, some of the bound phosphorus, particularly the portion bound to iron, may be released into the water column. As described in the In-pond Water Quality section, this phenomenon was observed in White Pond during stratified conditions.

Table J. Sediment Quality Summary

Site	Total Nitrogen (mg/kg)	Total Phosphorus (mg/kg)	Aluminum (mg/kg)	Calcium (mg/kg)	Iron (mg/kg)	Magnesium (mg/kg)
Homogenized composite of SG-1, SG-2, and SG-3	1000	96	1400	160	1600	240

4.2 Recreational Usage Summary

White Pond and adjacent shoreline areas are currently used for a variety of recreational activities, including but not necessarily limited to the following.

Fishing

Fishing is a popular activity in all seasons at White Pond (including winter fishing through the ice). The primary target is trout, which are stocked in spring and autumn and may hold over from season to season. However, bass and sunfish are also targeted. In previous years, broodstock Atlantic salmon from regional hatcheries were also occasionally stocked in White Pond and targeted by anglers. However, the Division of Fisheries and Wildlife (DFW) has discontinued stocking of this species due to the demise of both the state and federal Atlantic salmon hatchery programs in the region (Richard Hartley [DFW], personal communication, February 2015).

Shoreline fishing from the public access boat launch and White Pond Associates, Inc. beach is a popular activity outside of swimming season.

As a Great Pond, public access for fishing is provided at the state boat ramp on the eastern side of the pond. During this study, anglers were observed fishing from many different shoreline locations. However, shoreline fishing activity was mainly concentrated near the public access ramp. The shoreline areas of Town lands on the western end of the pond also attract some activity. Typically, no more than four or five anglers were observed to be using a given shoreline area at any one time.

Fishing from small boats and personal watercraft was also observed. These anglers typically focused on the deep hole or the mouths of shallow coves. No more than one or two small craft at a time were observed in active use for fishing.

It should be noted that the observations made during this study were outside of the presumed peak fishing days immediately following spring and fall stocking by the Division of Fisheries and Wildlife. Therefore, it is probable that daily fishing use is occasionally much higher than observed during this study.

Swimming

White Pond Associates is a private beach association that seasonally operates the pond's only official swimming beach on the eastern end of White Pond for its members. The membership varies from year to year but is usually around 700 families (White Pond Reservation Task Force 2002). Historically, workers at the Sperry-Rand research facility were allowed to use the Sachem's Cove beaches on the western end of the pond. However, since the property was purchased by the Town, swimming from the Sachem's Cove beaches has been

Dogs and people alike enjoy the beaches and cool waters of Sachem's Cove

discouraged. White Pond residents and those with deeded access to the pond, have swimming rights.

During this study, direct observations of swimming and wading at White Pond were concentrated on the White Pond Associates beach and in Sachem's Cove. Some of the swimmers used watercraft launched from the public access to reach Sachem's Cove. However, most swimmers appeared to directly access White Pond through Town land around Sachem's Cove.

On the hottest summer days, up to 25 people were observed swimming or wading at Sachem's Cove, despite the "No Swimming" signs posted on Town land. However, community observations suggest the number of visitors to the pond are often higher during the summer. Additionally, swimming or wading is likely to occur on a reduced scale throughout much of the year when the pond is ice-free. For example, even on a mild mid-May day five people were observed wading into the pond from Town land.

Swimming and wading activity was not limited to people. Dogs were also observed in significant numbers (up to seven at one time) on the White Pond shoreline and in the water itself.

Boating

In addition to the use of boats by White Pond residents and their guests, White Pond is publicly accessible for light craft boating (cartop, kayak, canoe and other non-motorized personal craft). Outboard motors are not allowed, although electric trolling motors are.

Limited parking at the public access point generally precludes more than a handful of boats from being on the pond at any one time. The number of watercraft observed at one time during this study was typically one or two. However, on warm summer weekends, the number of boaters increased to 15 to 20 at peak hours, mostly consisting of kayaks and inflatable personal watercraft.

Nature Study

Birdwatching, wildlife viewing, and botany are nature study recreational activities that can be enjoyed on and adjacent to White Pond. During this study, one individual was observed collecting aquatic macroinvertebrates from shallow waters near the public access ramp. Additionally, multiple classes from the Fenn School were observed learning about pond biology at the area including White Pond Associates beach and the public access ramp.

Trail Use: Hiking, Biking, Skiing and Horseback Riding

White Pond Reservation provides opportunities to hike, bike, or ride horses on the trails that cut through the woodlands abutting White Pond. These trails pass over steep and rocky but forested terrain with several spurs branching out toward the White Pond shoreline. Direct observation of hiking, biking, or horseback riding activity was not included in this study. However, the documentation of at least seven eroded trails near the shoreline suggests that these trails are frequently used for these purposes. Although not directly observed, cross-country skiing would also be expected during periods of snow cover (White Pond Reservation Task Force 2002).

Although the public trail system does not officially extend along beach and shorelines areas, small groups of people were also occasionally observed hiking around the pond along exposed portions of the pond shoreline.

Ice Skating

During cold weather, ice skating is popular on cleared sections of ice near the White Pond Associates beach. White Pond is a deep kettle hole so it tends to freeze later in the fall (more water volume to cool down), with ice cover lasting longer into spring.

Passive Recreation

Passive recreational activities were also observed at White Pond. Pond residents and public users were both observed engaging in sunbathing, reading, and relaxing on docks, the immediate pond shoreline or adjacent properties. The White Pond Associates beach and the Sachem’s Cove shoreline hosted the greatest number of passive recreational users on the immediate pond shoreline. Many of these users engaged in passive recreation between swimming or wading excursions into the pond.

4.3 Town-owned Parcels and Watershed Zoning

There are 122 parcels that lie wholly or partly within the White Pond watershed (Figure 8). The Town of Concord owns seven of these parcels, all of which are largely undeveloped.

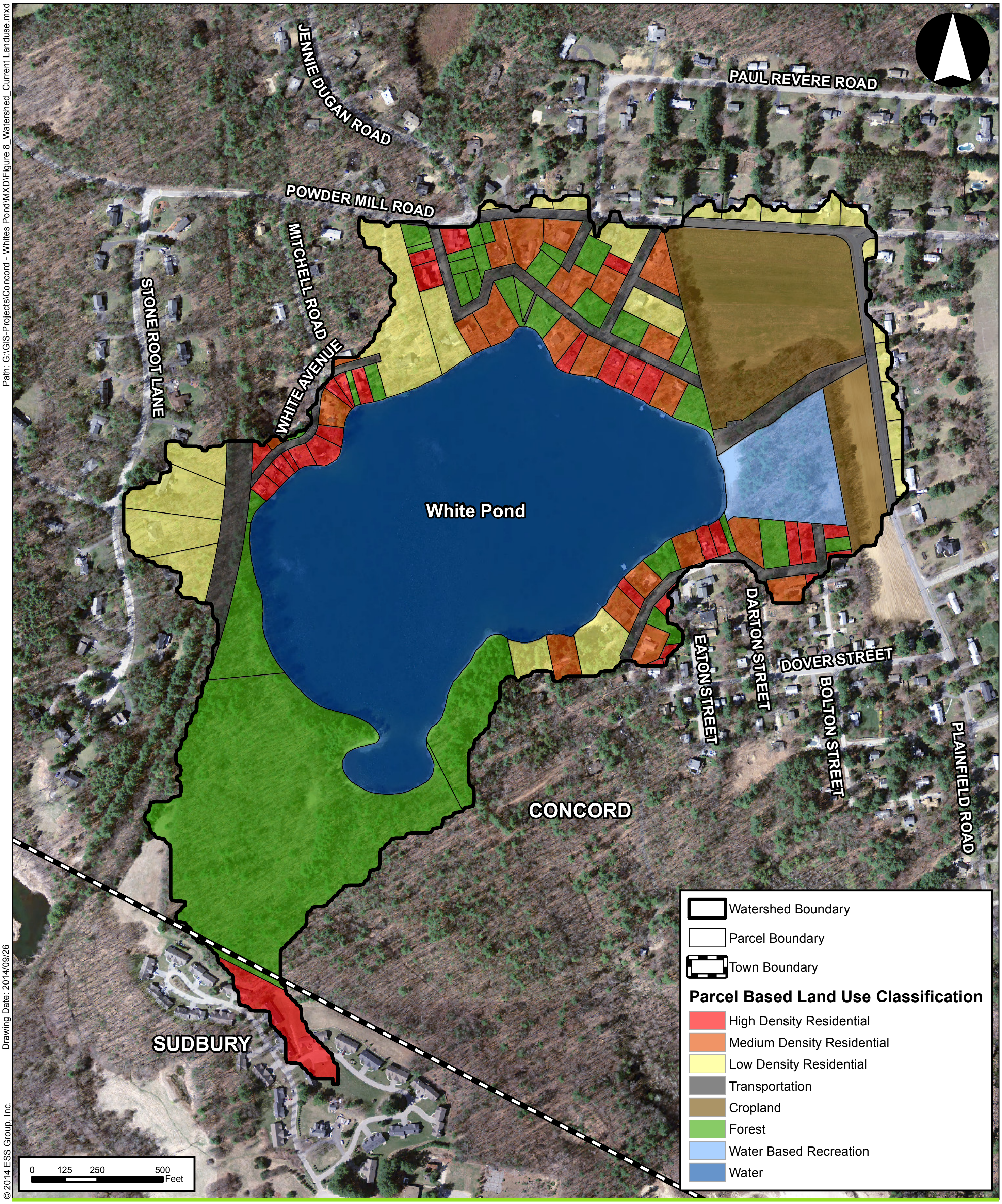
The largest of the seven Town-owned parcels is the portion of the former Unisys property within Concord, now known as the White Pond Reservation (parcel #3416-1). Previously, this and adjacent parcels in Sudbury were used as a 141-acre research campus by Unisys (formerly Sperry-Rand Corporation). The Town of Concord purchased approximately 40 acres of Unisys land in 1992, after the entire property was subdivided and sold. This purchase was contingent on Unisys cleaning up of hazardous waste contamination on the property. Volatile organic compounds (VOCs) had previously been spilled in two locations on the site. However, this contamination did not apparently reach or impact water quality in White Pond.or the White Pond Wells operated by the Town (Zitner 1991, Sprott 1991, ERM 2007 and 2009). With the primary exception of the White Pond Reservation, most Town-owned parcels in the watershed were acquired in the 1960s and 1970s, including the Quirk parcel (#3412-1), which was deeded as conservation land and is adjacent to the White Pond Reservation.

All of the other Town-owned parcels in the watershed are very small (less than 0.25 acre) and present minimal opportunity for use on their own other than as small forested lots (Table K). Additional details on Town-owned parcels in the watershed are presented in Table K. Deeds for the most recent transaction on each parcel are incorporated as Appendix E.

Zoning categories in the watershed include Residential A (minimum lot size 40,000 square feet) and Residential AA (minimum lot size 80,000 square feet). All Town-owned parcels within the watershed are zoned in the Residential A category. Two of these parcels are large enough to be subdivided while remaining above the minimum square-footage required in this zoning category (Table L).

One of these, #3412-1, comprises Town conservation land, is undeveloped, and lies just east of Sachem’s Cove. As conservation land, this lot is not developable. The second, #3416-1, is the White Pond Reservation on the former Unisys property, also abutting Sachem’s Cove and the western portion of the pond. This parcel is currently undeveloped but is not precluded from development, as long as development is in compliance with the deed restrictions (Table K).

White Pond Associates, Inc. also owns four parcels in the watershed, most of which are currently used for agriculture or recreation. All parcels are zoned as Residential A. Three of these parcels (#3269, #3271, #3272) are large enough to be subdivided and are currently undeveloped (Table L).



White Pond
Concord, Massachusetts

1 inch = 500 feet

Source: 1) Town of Concord, Parcel Data, 2010
2) USGS, Aerial Imagery 0.3m, 2013

White Pond
Current Land Use

Figure 8

Table K. Details on Town-owned Parcels in the White Pond Watershed

Parcel ID/Address	Year Acquired	Total Acres	Watershed Acres	Deed Restrictions/Notes	Suitable Uses				
					Description of Connectivity	Stormwater BMPs/ Erosion Control	Renewable Energy (Commercial Scale)	Community Wastewater Treatment or Pump Station	Conservation
3216 13 Tracy St	2001	0.18	0.18	Subject to zoning ordinances of the Town of Concord as of 1931	Groundwater recharge	No	No	No	Yes but low value
3240 2B Paul St	2005	0.12	0.10	Property taken for non-payment of taxes	Groundwater recharge	No	No	No	Yes but low value
3227 1A Tracy St	1970	0.08	0.08	Property taken for non-payment of taxes	Groundwater recharge	No	No	No	Yes but low value
3231 41A Powder Mill Rd	1962	0.10	0.08	Property taken for non-payment of taxes	Groundwater recharge	No	No	No	Yes but low value
3267 1 Seymour St	1970	0.09	0.09	Property taken for non-payment of taxes	Groundwater recharge	No	No	No	Yes but low value
336-1 and 3412-1 248 and 116 Shore Drive	1973	10.10	2.23	Conservation land	Abuts pond Direct surface runoff Groundwater recharge Wildlife corridor	Yes	No	No	Yes (current use)
3416-1 48B Fitchburg Tpk	1992	40.45	17.22	Subject to perpetual, non-exclusive easement, in favor of the adjoining land of the Town of Sudbury, allowing residents of Sudbury access to the premises for passive recreational use (specifically excluding swimming and motorized vehicles and subject to reasonable rules and regulations of the Town of Concord). Subject to easement providing Unisys Corporation with access to the extent reasonably necessary to perform its obligations for site remediation, together with any necessary access to utility connections and easements to utility companies.	Abuts pond Direct surface runoff Groundwater recharge Wildlife corridor	Yes	Possibly	Possibly	Yes

The remaining 110 parcels within the watershed are privately-owned and 83 of them have been developed to some extent (Table L). Of these, only one parcel is large enough to be subdivided under existing zoning regulations. This parcel, #3215, is zoned as Residential A and lies along the northwest shore of White Pond. None of the remaining 27 undeveloped parcels are large enough to be subdivided under current zoning by-laws.

Table L. Overview of All Parcels in the White Pond Watershed

Ownership	Total Parcels in Watershed	Watershed Acreage	Developed	Undeveloped	Subdivisible-Developed	Subdivisible-Undeveloped
Public – Town	7	20	0	7	0	2
Public – State	1	1	1 (access road)	0	0	0
Private – White Pond Associates	4	16	1	3	0	3
Private - Other	110	76.5	83	27	1	0

4.4 Watershed Modeling

Hydrologic Budget

The average annual precipitation for White Pond is estimated to be 44.41 inches, based on Hanscom Field Airport records. Estimated average water input to White Pond from surface water (stormwater), groundwater, and direct precipitation is 0.022, 0.218 and 0.097 cubic feet per second (cfs), respectively, for a total average annual flow of approximately 0.337 cfs (Appendix C). Groundwater flow contributes the largest portion (65 percent) to the total pond inflow, while direct precipitation accounts for 29 percent and surface inflow the remaining 7 percent. A summary of key hydrologic parameters for White Pond is presented in Table M.

Table M. Summary of White Pond Hydrology

Element	Value
Watershed Area	113.5 acres
Pond Area	39.4 acres
Pond Circumference	6,180 feet
Pond Volume	47 million cubic feet
Average Water Depth	27.2 feet
Average Groundwater Seepage Inputs	0.218 cfs
Average Direct Precipitation	0.097 cfs
Average Surface Water Inputs (Total)	0.022 cfs

Based on total pond volume (47 million cubic feet) and the estimated flow through the system, average detention time was calculated to be 1,602 days (4.4 years). Flushing rate is the inverse of detention time and represents the number of times per year the pond volume is replaced. White Pond is flushed approximately 0.23 times per year. This indicates that water moves through very slowly, providing a long period of time for water (and associated loads of nutrients and pollutants) to interact with the biological, physical, and chemical conditions in the pond.

Phosphorus Loading

For the current study, a calculation of minimum phosphorus load was made using a mass balance equation. The minimum phosphorus load delivered to White Pond was determined to be 0.02 $g/m^2/yr$ (3 kg/yr), based on the in-pond nutrient concentrations observed during the study (Table N).

The actual load of phosphorus will exceed the estimated minimum load as a consequence of loss processes that reduce the in-pond concentration over time. By taking these loss processes into account, a more detailed and realistic estimate of phosphorus loading can be obtained.

Modeling that incorporates loss processes yielded phosphorus loading rates between 0.04 $g/m^2/yr$ (6 kg/yr) using the Vollendweider (1975) model and 0.14 $g/m^2/yr$ (22 kg/yr) using the Reckhow General (1977) model (Table N). The average predicted phosphorus load for all models was 0.08 $g/m^2/yr$ (13 kg/yr).

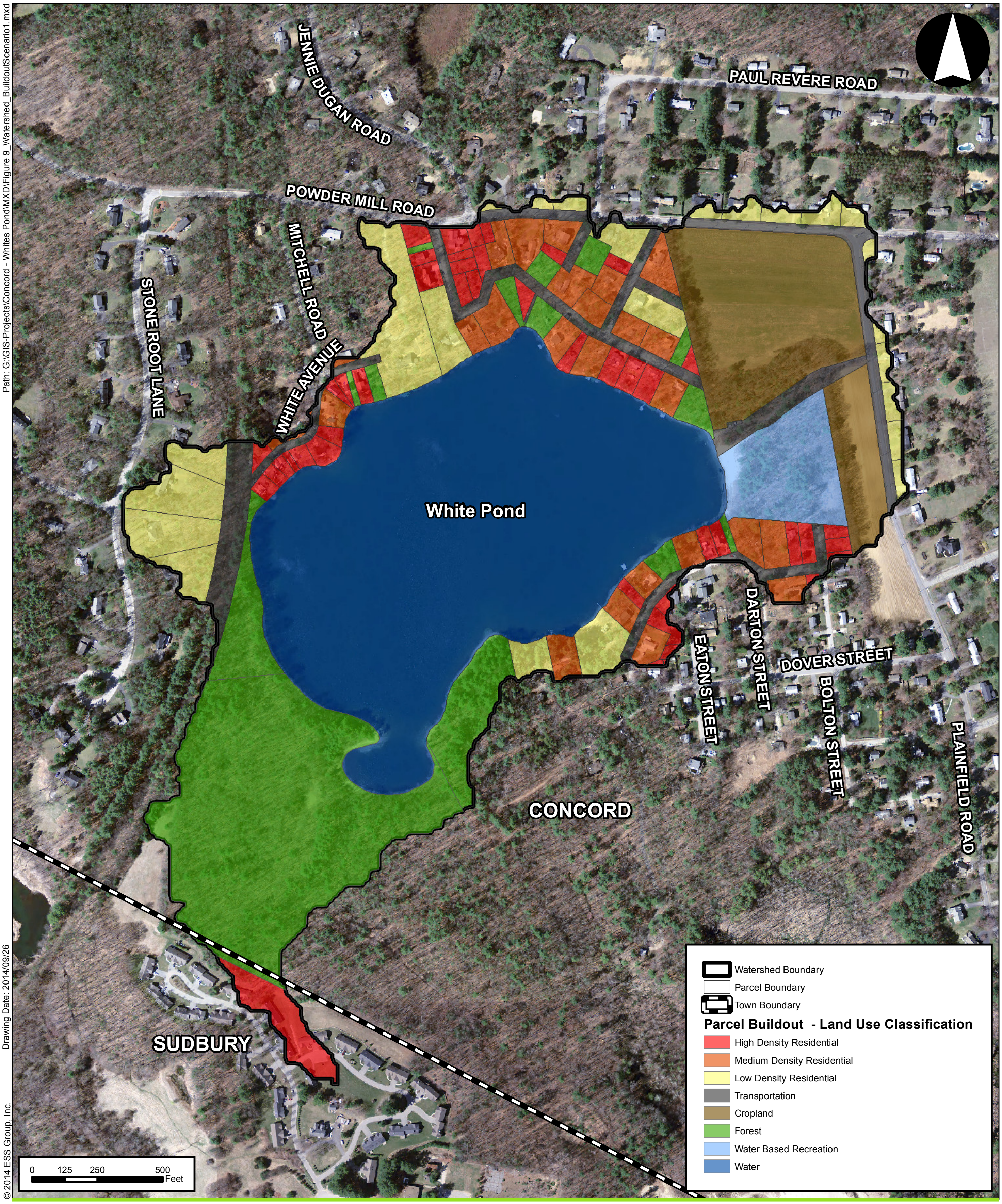
The average of phosphorus loads estimated for the pond through the in-pond models (13 kg/yr) is below the permissible load of 22 kg/yr. However, given the limitations of the models, these loading estimates should be used with caution and it should not be assumed that the pond can assimilate larger phosphorus loads than it already receives. Further caution is warranted in consideration of Walker and Ploetz's (1989) previous phosphorus modeling results, which suggested loading of approximately 22 kg/yr to White Pond at that time, most of which resulted from watershed stormwater sources. Therefore, a management approach that addresses controllable current and potential future sources of phosphorus is recommended to minimize phosphorus loads to the pond.

Table N. Summary of White Pond Nutrient Loading Model Results

Nutrient	Model Output	Value
Phosphorus	Model Minimum (Mass Balance) Load	3 kg/yr
	Model Average Load	13 kg/yr
	Model Maximum (Reckhow) Load	22 kg/yr
	Permissible Load	22 kg/yr
	Critical Load	44 kg/yr
Nitrogen	Minimum (Mass Balance) Load	191 kg/yr
	Bachmann Load	448 kg/yr

Of the potential phosphorus sources identified in this study, surface watershed sources are by far the most important, contributing 54 percent of the total load (Table O). An estimated 14 percent is sourced from stormwater flows off of the erosional areas around the pond alone. Groundwater sources contribute 15 percent with an additional 14 percent from atmospheric deposition. Swimmers are estimated to contribute 3 percent of total loading. Other sources (dogs, horses, waterfowl, fish stocking, and internal recycling from the sediments) together are estimated to contribute 14 percent of total loading.

Path: G:\GIS-Projects\Concord - Whites Pond\MXD\Figure 9. Watershed_BuildoutScenario1.mxd



Drawing Date: 2014/09/26

ess group
environmental consulting & engineering services

White Pond

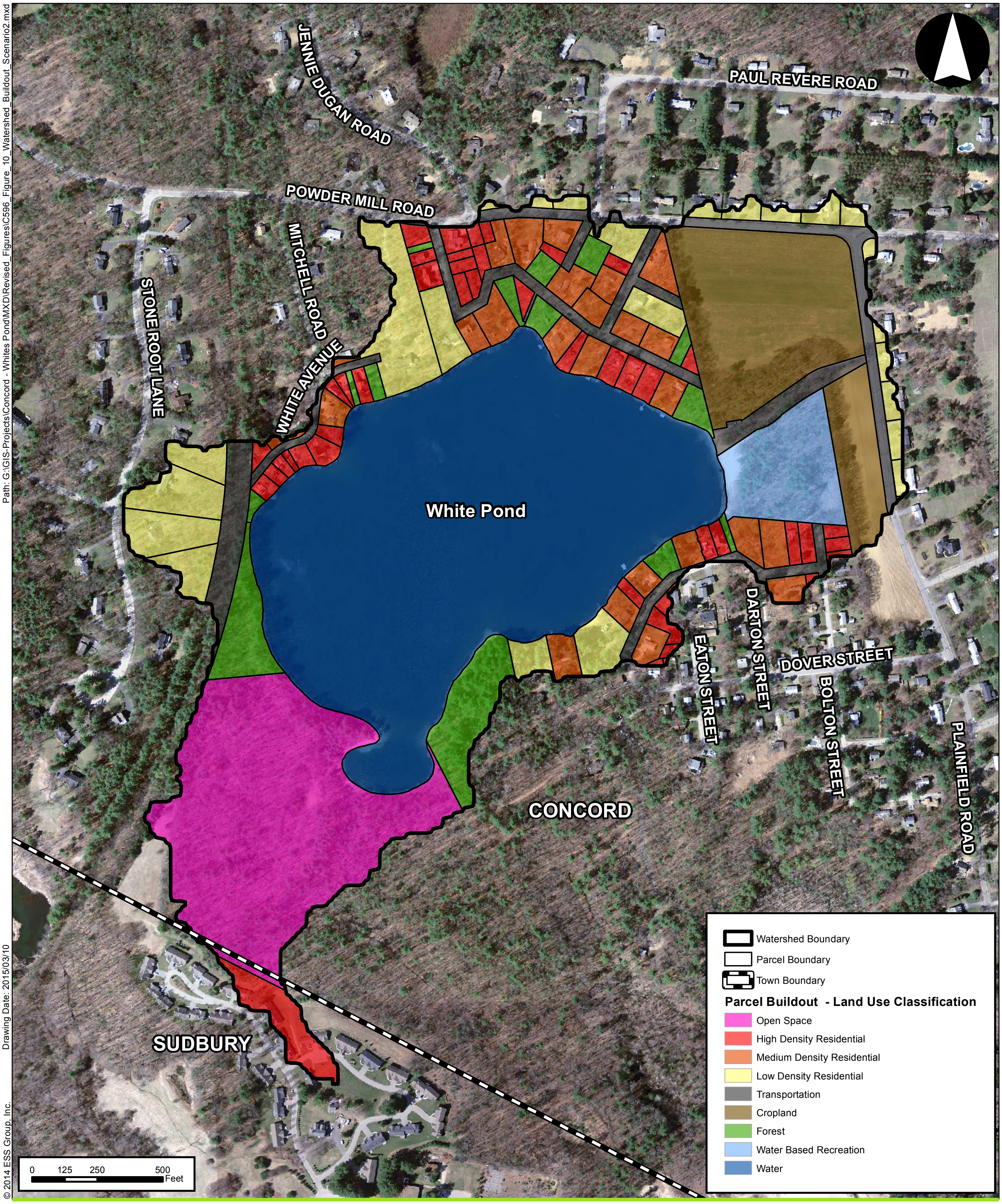
Concord, Massachusetts

1 inch = 500 feet

Source: 1) Town of Concord, Parcel Data, 2010
2) USGS, Aerial Imagery 0.3m, 2013

White Pond Watershed
Build-out Scenario 1

Figure 9



ess group environmental consulting & engineering services

White Pond
Concord, Massachusetts

1 inch = 500 feet

Source: 1) Town of Concord, Parcel Data, 2010
2) USGS, Aerial Imagery 0.3m, 2013

White Pond Watershed
Build-out Scenario 2

Figure 10

Each of these estimates carries a degree of uncertainty. Inputs that were not directly measured were based on published literature values coupled with field observations and, in the case of swimmers, community input. The assumptions associated with each estimate are as follows:

- Nutrient inputs from atmospheric deposition were based on regional values reported by Koelliker et al. (2004) for phosphorus.
- Estimates of nutrient inputs from swimmers were based on methods used by Colman and Friesz (2001) for Walden Pond. An average of 100 swimmers per day from June through August was assumed.
- Direct dog waste contributions were based on the equivalent of one medium-sized dog defecating in or immediately adjacent to the water each day. Although field observations suggest a higher number of dogs visit the pond and surrounding lands, it was assumed that most dogs will not defecate in the water. Dog waste not directly deposited in the pond is accounted for in the watershed sources.
- Direct horse waste contributions were based on the equivalent of one 500-kg horse defecating in or immediately adjacent to the water once a month. Horse waste not directly deposited in the pond is accounted for in the watershed sources.
- Waterfowl contributions were estimated based on the value used by Colman and Friesz (2001) for Walden Pond, adjusted for surface area
- Fish stocking contributions were based on phosphorus content values reported by Tanner et al. (2000) and the assumption that 10 kg of the fish stocked (including spring and fall) go unharvested by anglers each year.

Table O. Estimated Annual Phosphorus Load by Source

Source	Percentage of Phosphorus Load
Atmospheric Deposition	14
Groundwater	15
Watershed	54
(Shoreline Erosional Areas: 14%)	
(Other Watershed Runoff, including pond access road: 40%)	
Swimmers	3
Dogs	6
Fish Stocking	2
Horses	3
Waterfowl	3
Sediment (Internal Recycling)	<1
Total	**100**

Nitrogen Loading

The minimum nitrogen load delivered to White Pond was determined to be 1.20 $g/m^2/yr$ (191 kg/yr), based on the in-pond nutrient concentrations observed during the study (Table P).

As with phosphorus, the actual load of nitrogen will exceed the estimated minimum load as a consequence of loss processes that reduce the in-pond concentration over time. By taking these loss processes into account, a more detailed and realistic estimate of nitrogen loading can be obtained. For White Pond, the Bachmann (1980) model was used to derive an improved estimate of current nitrogen loading.

Based on the results of the Bachmann model, nitrogen loading was estimated to be 2.81 $g/m^2/yr$ (448 kg/yr) (Table P).

Of the potential nitrogen sources identified in this study, groundwater sources are by far the most important, contributing 69 percent of the total load (Table P). This is similar to the percentage of water supplied to White Pond through groundwater. Additionally, nitrogen moves much more easily through groundwater because it does not bind to soil particles as readily as phosphorus. Therefore, the large portion of nitrogen from groundwater sources does not necessarily suggest a major septic loading problem. The remaining primary nitrogen sources in the White Pond watershed include 13 percent from watershed runoff with an additional 18 percent from atmospheric deposition.

Table P. Estimated Annual Nitrogen Load by Source

Source	Percentage of Nitrogen Load
Atmospheric Deposition*	18
Groundwater	69
Watershed	13
(Shoreline Erosional Areas: 5%)	
(Other Watershed Runoff, including pond access road: 9%)	
Total	**100**

*Based on regional values reported by USGS (2004)

Permissible and critical loading limits for nitrogen are not typically developed, owing to the less predictable relationship between nitrogen, pond hydrology, and primary productivity. Although nitrogen data are very useful in understanding in-pond conditions and processes and to assess management needs for water supplies, phosphorus remains the logical target of management actions aimed at maintaining water quality conditions in White Pond.

Watershed Build-out and Projected Changes in Phosphorus Loading

The primary current land use in the White Pond watershed includes White Pond itself (water), covering approximately 39.4 acres (Table Q, Figure 8). Forest is the second most extensive land use at 25.9 acres. All residential land use combined totals to 23.8 acres, of which 5.6 acres is developed as high density residential (i.e., lot size is less than 0.25 acre). Other land uses include (in descending order of area) cropland, transportation, and water-based recreation (the White Pond Associates beach). Changes in land use under the assumptions of the two watershed build-out scenarios is presented in Table L.

Table Q. Summary of Land Use in the White Pond Watershed

Land Use	Current (Acres)	Build-out Scenario 1 (Acres)	Build-out Scenario 2 (Acres)
Agriculture	11.9	11.9	11.9
Forest	25.9	23.3	13.3
Wetland	0.0	0.0	0.0
Open/Cleared Land	3.9	3.9	13.9
High Density Residential (less than 0.25 acre lot)	5.6	7.2	7.2
Medium Density Residential (0.25 to 0.5 acre lot)	7.0	8.0	8.0
Low Density Residential (greater than 0.5 acre lot)	11.2	11.2	11.2
Transportation	8.3	8.3	8.3
Water	39.4	39.4	39.4
Total	**113.2**	**113.2**	**113.2**

The first land-use-based modeling scenario assumed residential build-out on all developable lots, excluding land owned by White Pond Associates, Inc., White Pond Reservation land and Town Conservation land (Figure 9). White Pond Associates land was assumed to remain in its current state as agricultural, forest, and recreational land base on the understanding that this organization intends to retain current land uses for the benefit of its membership (WPAC personal communication).

The second scenario assumed the same residential build-out of the White Pond watershed but also included conversion of White Pond Reservation land from forest to open/cleared land (Figure 10).

Currently, there are few direct nutrient pathways from the watershed to White Pond. However, with additional development and the associated increase in impervious surfaces likely to result, the attenuation coefficient would be expected to rise (i.e., nutrients exported in the watershed would have more direct pathways to the pond), However, construction of impervious surfaces (such as, roofs and roads), which prevent natural infiltration would be expected to accelerate the conveyance of stormwater and associated nutrients. This was accounted for by increasing the model attenuation coefficients in the build-out scenarios.

Under the first build-out scenario, i.e., where only the remaining developable small lots in the watershed are developed as residential properties and the Town land on the southwestern margin of White Pond is left as is, an increase of 1.0 kg/yr of phosphorus loading could be expected (Table R). This would result in a total annual phosphorus load approaching 14 kg/yr.

Under the second built-out scenario, installation of one or more solar arrays also occurs on Town land (currently forested portions of the White Pond Reservation). Given this scenario, the land-use-based phosphorus loading rate would be expected to increase due to conversion of forest to open land. Conservatively assuming that most of this parcel within the watershed would be needed to achieve the 3 to 5 MW production identified in the Concord Solar Siting Committee report (2011), land-use-based phosphorus loading would increase by an additional 2.1 kg/yr beyond that of the first built-out scenario (Table R). This would result in a total annual phosphorus load just over 16 kg/yr. However, it is expected that the solar array on this parcel could be designed to minimize or avoid generation of runoff through on-site infiltration.

Table R. Anticipated Changes in Phosphorus Loading under Watershed Build-out Scenarios

Land Use	Current		Build-out Scenario 1		Build-out Scenario 2	
	kg/yr	Percent	kg/yr	Percent	kg/yr	Percent
Agriculture	13.5	24	13.5	23	13.5	21
Forest	6.4	11	5.8	10	3.3	5
Wetland	0.0	0	0.0	0	0.0	0
Open/Cleared Land	3.1	6	3.1	5	11.1	17
High Density Residential (less than 0.25 acre lot)	8.3	15	10.6	18	10.6	17
Medium Density Residential (0.25 to 0.5 acre lot)	5.1	9	5.8	10	5.8	9
Low Density Residential (greater than 0.5 acre lot)	3.3	6	3.3	6	3.3	5
Transportation	14.4	26	14.4	25	14.4	23
Water	1.8	3	1.8	3	1.8	3
Attenuation Coefficient	0.23		0.24		0.26	
Total Annual Phosphorus Load	**13.0**		**14.0**		**16.1**	

Note: Phosphorus export coefficients based on median value predicted by Reckhow (1980)

In sum, due to the minimal opportunity for additional urban development in the watershed, significant increases in nutrient loading due to development are unlikely to occur. However, management of any additional loading is recommended to mitigate impacts on White Pond. At least some of the increased nutrient loading could be mitigated by minimizing the area temporarily disturbed during construction, keeping access roads to a minimum, and implementing appropriate stormwater treatment and infiltration BMPs onsite, pursuant to municipal stormwater regulations and state stormwater management standards.

5.0 IDENTIFICATION OF KEY MANAGEMENT CONCERNS

The primary management concerns at White Pond are described in the following sections.

5.1 Decreased Water Quality and Quantity

Community concerns center around a negative trend in water quality, particularly with regard to water clarity. Walker (2014) suggests a parabolic trend in summer water clarity at White Pond during the 1987 to 2013 period. Improving conditions were observed through 2005, followed by declines from 2006 to 2013.

The primary concern with water levels in White Pond is the perception that they have been low for multiple seasons and are continuing to fall. Lower water levels result in docks out of water, reduced beach swimming area and reduced habitat volume in the pond. Water quality issues could potentially result due to reduced dilution of pollutants and shifts in thermal profiles and light penetration.

Temperature plays a key role in pond hydrologic, physicochemical, and biological processes, affecting evapotranspiration, availability of dissolved oxygen, metabolic speed, and the timing and nature of pond mixing, among other things. Although existing volunteer-collected data do not show a clear trend in temperatures at White Pond over time, regional annual average temperatures in eastern Massachusetts have warmed since the 19^{th} century. These warming temperatures have been accompanied by later average ice-on and earlier average ice-off dates on area water bodies (Blue Hill Observatory 2014). As such, it is anticipated that White Pond has likely warmed over time, as well.

Dissolved oxygen and temperature profiles suggest that the volume of the pond retaining cool water with sufficient oxygen to support coldwater fish (e.g., trout) has declined since the early 1960s. Records from the Massachusetts Division of Fisheries and Wildlife indicate that nearly 35 percent of the pond (by volume) was considered to be supportive of trout during the late summer months at that time. By 1977, the percentage of trout habitat measured by the Massachusetts Division of Fisheries and Wildlife had declined to 19 percent. Based on data collected specifically for this study, trout habitat currently occupies approximately 16 percent of the pond volume in White Pond.

There is also some community concern with pathogens at White Pond, stemming primarily from an elevated occurrence of giardiasis and cryptosporidiosis cases in Concord during the summer and early fall of 1999. Although White Pond was not directly confirmed as the source of the outbreak, the majority of those infected reported exposure to water in White Pond prior to becoming ill (Division of Epidemiology and Immunization 2000).

> "As at Walden, in sultry dog-day weather, looking down through the woods on some of its bays which are not so deep but that the reflection from the bottom tinges them, its waters are of a misty bluish-green or glaucous color."
> -Henry David Thoreau

Regional annual precipitation has also demonstrated a change over time, with a trend toward wetter years but greater interannual variability (Blue Hill Observatory 2014). This trend may be expected to impact the hydrologic budget for White Pond, including the contribution generated by stormwater, which tends to deliver the highest concentrations of phosphorus to the pond.

5.2 Swimming

Swimming and wading from shore on Town land has been cited as a concern because it leads to additional erosion of slopes leading down to the pond and results in litter problems. Those familiar with the results of the Colman and Friesz (2001) study of Walden Pond and the subsequent "Don't Pee in the Pond" campaign may also be concerned about the potential phosphorus contribution from large numbers of swimmers.

These activities have been presumed illegal due to the posting of "No Swimming" signs and past enforcement by Town rangers. However, there is some question as to whether swimming from Town shorelines actually violates a sanctioned Town by-law, rule, or regulation. The only documents reviewed that appear to restrict swimming from Town land are the White Pond Reservation rules and the deed for the White Pond Reservation parcel. Additionally, minutes from the Board of Selectmen meeting on November 2, 1992 indicate that the Board endorsed the Preliminary Land Management Plan for White Pond Reservation, which indicated permitted recreational uses of hiking, horseback riding, picnicking, cross-country skiing, fishing, and skating.

Concerning the White Pond Reservation rules, there is some confusion regarding whether swimming is prohibited and whether any formal action was taken over a decade ago when the "No Swimming" signs were posted on Town land.

Regarding the deed restrictions on the White Pond Reservation parcel, those accessing the pond from Sudbury (via Frost Farm Village Road) are permitted access to the pond for passive recreation but access for swimming is specifically prohibited. However, no such restriction appears for those accessing the White Pond Reservation parcel from within Concord.

5.3 Sanitary Facilities

Sanitary facilities are not available for those accessing White Pond through White Pond Reservation or Town Conservation Land. Sanitary facilities are available to users of the White Pond Associates beach on a seasonal basis. However, those using the public access boat ramp and parking area do not have sanitary facilities available.

The lack of appropriate public sanitary facilities is inconvenient to users of the pond and may negatively impact water quality in White Pond.

5.4 Future Impact of Bruce Freeman Rail Trail

Based on surveys completed on the Bruce Freeman Rail Trail in Chelmsford, the number of users in a given location typically approached or exceeded 1,000 per day on Saturdays (Friends of the Bruce Freeman Rail Trail 2014). Accordingly, it is not unreasonable to assume that the Bruce Freeman Rail Trail will likely increase the number of visitors to the White Pond area by thousands per year. Although many people would be expected to simply pass through on the BFRT, the actual number of people leaving the BFRT to explore White Pond Reservation and the pond itself could be substantial compared to the current number of visitors. The primary concern is that additional foot, bicycle, and pet traffic could exacerbate the current problems with erosion around the pond and overwhelm the Sachem's Cove area in particular.

5.5 Future Impact of Alternative Uses of Town Parcels

Seven Town-owned parcels are located at least partially within the White Pond watershed. Most of these parcels are very small, set back from the immediate shoreline and will have a negligible impact on White Pond regardless of use. Town conservation land is protected from development. Conversely, the Town-owned parcel associated with the White Pond Reservation has been the subject of various development proposals since being purchased by the Town in 1992, including housing, wastewater treatment or pumping, and a solar energy installation. Each of these uses would imply a change to existing land use and increased imperviousness. However, none of the proposed projects has yet gained significant traction or reached the permitting-level design stage.

5.6 Changes in Aquatic Vegetative Cover

Some shoreline residents express concern that the growth of aquatic vegetation in White Pond has expanded over the years, decreasing the amount of exposed sand substrate. The aquatic vegetation survey conducted as part of this study was limited to a brief period of time and indicated that aquatic vegetation in White Pond consists of low-growing native plants and is confined to a narrow, broken band along the shoreline. Although current conditions may represent an increase in plant cover from past conditions, the dominant species observed (spikerush and golden hedge-hyssop) are not typically problematic. These plants may be expected to shift their distribution based on trends in water level, clarity, and availability of nutrients in the sediments. Should an invasive aquatic plant species be introduced to White Pond, the potential exists for much larger shifts in vegetative cover and biovolume.

6.0 RECOMMENDED MANAGEMENT PROGRAM

Given the limited scope of issues currently impacting White Pond, the management options evaluated were focused on improvement of the way public access to the pond is managed and prevention of future problems.

Recommended actions are presented in the order of priority. A summary table of the management plant with costs is presented in Appendix F.

6.1 Stabilize Areas of Recurring Erosion

Eleven areas of significant erosion were identified adjacent to the White Pond shoreline. Based on the results of stormwater sampling and the hydrologic and nutrient budgets developed for White Pond, stabilization of these areas is recommended to prevent delivery of sediments and associated nutrients.

Installation of regraded gravel trail with timber curbing (left) and and bioretention area (right).

These include the areas on White Pond Reservation and Town conservation land, as well as Stone Root Lane common land and White Pond Associates, Inc. land. Stabilization of any other erosional areas on private land adjacent to the pond should also be encouraged as a priority management action.

Projects of this type in the buffer zone of White Pond or within a Priority Habitat of Rare Species would require filing an NOI and coordinating with NHESP on potential Massachusetts Endangered Species Act (MESA) issues. An NOI specific to implementation of erosion controls on Town lands would be expected to cost on the order of $20,000 to $30,000, inclusive of design costs.

Construction of erosion controls would vary depending on the final design and conditions of the permitted project. However, costs on the order of $50,000 to $80,000 should be expected for a project limited to Town lands.

6.2 Manage Public Use of Town Lands

Improving the management of recreational usage of White Pond and adjacent Town lands is recommended to reduce sediment and nutrient loading, as well as provide an enjoyable public user experience.

Improve Signage

Replacement and improvement of signage on Town lands for directional, educational, and cautionary purposes is expected to help channel users to appropriate trails and pond access locations, reducing the future occurrence of erosion and slope failure.

Educational signage would reinforce the message that wandering off-trail has been directly linked to the degradation of White Pond Reservation and the pond itself.

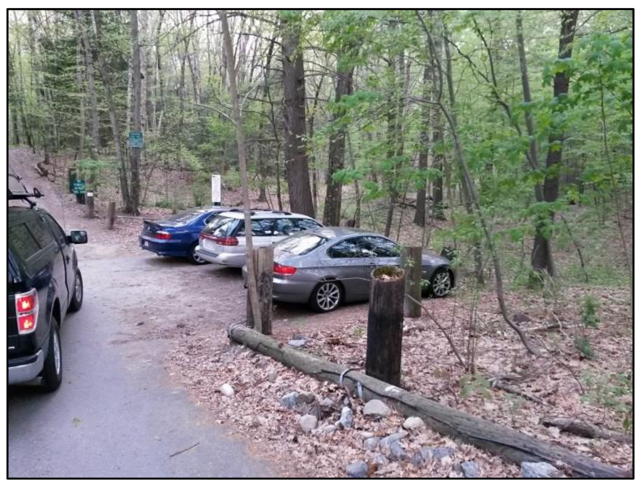
Costs for directional and cautionary signage are typically low. Full-color educational or interpretive signage can be very effective at conveying the “why” of trail and pond use rules but are typically more complex and may cost several hundred to a thousand dollars or more (designed and installed).

Improve Trail System on Town Land

Some of the trails through White Pond Reservation and Town conservation land pass through sensitive areas, such as high slopes adjacent to the pond. In general, these primarily include unblazed or connector trails. The Town should evaluate whether these trails need to be closed and/or restored. Revegetation and/or fencing that restricts passage but not visibility (so-called “cow fencing” similar to that used at Walden Pond [DCR 2013]) are options to discourage off-trail wandering.

Additionally, the Town should consider the possibility of increased demand on trails through White Pond Reservation due to implementation of Phase 2C of the Bruce Freeman Rail Trail.

Regular inspection and maintenance of the trail system on Town lands will prevent the development of rills, slope failure, or other undesirable features. A structured and funded program will also give the Town the opportunity to identify and address areas where off-trail use could lead to future problems.



Existing parking at the end of Varick Street. Addition of two to three more parking spots would be feasible but not without impacting some vegetation on conservation land.

Selectively Add Parking

Opportunities to add public parking are limited. However, it may be possible to add a few spaces to the existing parking area at the end of Varick Street. Currently, there is parking for three to four vehicles on Town land at 24B Hemlock Street, which is outside the White Pond watershed. An additional two to three parking spots could be added for a total of six to seven vehicles, although there would likely be at least some indirect impact to existing trees to accommodate the expanded parking.

Alternatively, other nearby Town-owned parcels, such as 18B, 12B, and 13B Hemlock Street as well as 4B Valley Street could host parking and still be within easy walking distance of White Pond Reservation and adjacent conservation land. Adding parking at one or more of these parcels would allow the Town to retain conservation land at 24B Hemlock Street in its current state.

All of these items could be addressed in a Trail Management Plan developed specifically for the White Pond Reservation and adjacent conservation land. The plan should be expected to cost between $5,000 and $15,000, depending on the level of detail required.

6.3 Provide Public Toilet and Trash Receptacles

The OFBA boat launch and adjacent parking area on the east side of White Pond are frequented by the public, including boaters and anglers who could benefit from public sanitary facilities and adequate rubbish receptacles. The lack of facilities that are clearly intended for public use results in littering and public urination at the public access ramp, which are undesirable from public safety, public health, aesthetic and water quality perspectives. This area is managed by the Massachusetts Division of Fisheries and Wildlife.

Town lands abutting White Pond could also benefit from a public toilet and rubbish receptacle. Although one or more trash receptacles could be maintained with a small electric utility vehicle, it would be difficult to service a public toilet located at or adjacent to Sachem's Cove without extending a service road several hundred feet from the end of Varick Street. Alternatively, public toilet facilities could be placed and serviced at the Varick Street entrance, with signage added at Sachem's Cove and along the trail system to clearly direct the public to the facility.

Provision of portable public toilet facilities and a trash receptacle could be provided at minimal cost. For example, portable toilets can rented for as little as $100/month, which includes delivery and weekly maintenance costs.

If a permanent structure is desired instead, the costs should be expected to be significantly higher, due to the requirement for design, permitting requirements would be associated with construction of a permanent structure. Also, construction of a permanent restroom structure would require sponsorship of (or permission for) the project by the owner of the land where the structure is to be sited.

6.4 Public Education and Outreach

Public education and outreach will raise awareness of issues at White Pond and encourage public involvement in its protection and management as a community resource, particularly with regard to prevention of future problems. Education and outreach may take many forms. These may include postings at the public access launch, distribution of materials to White Pond area residents and White Pond Associates, Inc. members, school programs, booths at Town-sponsored events, and website postings, to name a few.

Costs to implement public education and outreach programs vary widely, depending on the approach and number of people or households targeted. Professional design and production of a brochure or basic interpretive sign is typically $2,000 to $3,000.

Typically, there is no permitting involved in public education. However, actions that require fill, excavation, or structural components may require permits, particularly if they occur near a wetland resource area or other protected resource.

Prevent Introduction of Aquatic Invasive Species

White Pond does not currently appear to host aquatic invasive species. This is an uncommon condition for a publicly accessible water body in eastern Massachusetts and should be preserved.

Although White Pond does not receive an extreme amount of high-risk boating (due to motor restrictions and lack of trailer parking), a volunteer boat monitor program at the public access boat launch would be an excellent way to prevent introduction of exotic species. The Massachusetts Weed Watchers program, sponsored by the Department of Conservation and Recreation Lakes and Ponds Program, provides training and technical assistance to volunteer groups interested in monitoring and reporting exotic species. Either of these programs would be helpful for preventing establishment of new exotic species in White Pond.

Encourage Proper Onsite Septic System Maintenance

A number of septic systems in the White Pond watershed have been recently replaced or upgraded and they are not currently considered to be a primary source of phosphorus to White Pond. However, the density of developed parcels in the watershed suggests the hazard of future system failure. Therefore, it is imperative that septic systems in the watershed be properly inspected and maintained or upgraded, as necessary. Targeted education of homeowners in the watershed may be very helpful toward this end.

6.5 Implement/Upgrade Stormwater BMPs

The catch basin at the White Pond public access boat launch quickly reached capacity, allowing untreated or minimally treated stormwater to flow directly down to the pond.

The public access road and boat launch would be locations to target implementation of new stormwater BMPs or upgrade of previously installed ones. Maintenance of the existing structures is critical but complicated. Based on observations of stormwater flow during the November 27, 2013 storm event, the existing catch basins only capture a small portion of moderate to large events before backing up and allowing untreated stormwater to flow down to the pond.

Although there is room to develop stormwater BMPs on the small Town-owned parcels to the north of White Pond, there is minimal current need to do so. Investigations of the neighborhoods around these parcels did not reveal the presence of significant stormwater pathways to the pond. With the exception of 2A Paul Street, the sandy soils in this area are hydrologic class A, meaning that they are exceptionally well-drained and have superior infiltration capacity. Therefore, at the current density of development, there is little overland runoff generated from these areas. Rather, the primary sources of overland stormwater flow to White Pond are the steep banks immediately adjacent to it (as identified in Figure 4). These problem areas may not require BMPs beyond the erosion control and slope stabilization techniques recommended in Section 6.1.

Rain gardens are an excellent way to retain and infiltrate stormwater on most residential sites.

If stormwater runoff becomes a problem locally around watershed dwellings and roads, residential rain gardens should be encouraged to enhance infiltration. These can usually be implemented by residents. However, assistance from an experienced professional familiar with rain garden design will generally result in the most satisfactory results, both aesthetically and functionally.

The design of improved stormwater BMPs is beyond the scope of this study. However, selection of locations for the BMPs, along with design and permitting would be expected to cost $10,000 to $20,000 depending on the scope of the design. Construction costs for new BMPs should be expected to require a minimum of $25,000 but potentially much more, depending on the technology used and area involved. Ongoing maintenance costs should also be expected on at least a monthly basis.

6.6 Biomanipulation (Optional)

Biomanipulation involves the introduction of top-down (predators/herbivores) or bottom-up (prey/plants/pathogens) biological controls to effect changes in the pond food web. At White Pond, the ultimate target of a biomanipulation program would be the phytoplankton community. Therefore, top-down biomanipulation is anticipated to have the most potential for positive impact.

Biomanipulation techniques require a significant amount of time to become effective, often five to seven years. Additionally, this method may require multiple introductions of the biological control agent until it becomes sufficiently established to achieve the desired level of control. As such, biomanipulation is only currently recommended as a low-priority or alternative in-pond option for control of excess planktonic algae or plant growth. Biomanipulation would become a higher priority option if algae blooms or plant growth become severe enough to restrict recreational opportunities or create a public health nuisance *and* the community does not desire to implement chemical control options (i.e., algaecides or herbicides).

One way to influence phytoplankton is by changing the structure of the zooplankton grazing community to favor species that are more effective grazers. Stocking of zooplankton is not a widely used approach due to the difficulty and cost that would be involved in harvesting or culturing a large enough population sufficient to influence a deep kettle pond the size of White Pond. Rather, stocking of top-level piscivorous (predatory) fish is the preferred approach. Such an introduction would be expected to increase predation pressure on planktivorous forage fish (e.g., sunfish, minnows). Since forage fish are important predators on zooplankton (with a preference for large-bodied species), a reduction in forage fish populations could relieve predation pressure on zooplankton, thereby resulting in more large-bodied zooplankton to graze on phytoplankton. An alternative approach would be to directly harvest planktivorous fish from the pond. Neither of these approaches can be fully recommended without more direct study of the desired target organisms.

Lastly, because biomanipulation relies on very complex relationships that are highly sensitive to random disturbances, it is possible for outcomes to vary significantly from expected. Therefore, success of a biomanipulation program would require a thorough understanding of biological community and population structure prior to implementation. Additional close monitoring would also be required for the life of the program to ensure that proper adjustments could be made in a timely matter. These necessities add significantly more to cost than the actual fish stocking.

Biomanipulation is only recommended as an alternative management action if algae blooms intensify or become more frequent. A biomanipulation project at White Pond would first require a feasibility study. This would primarily consist of an in-depth fisheries survey to better define the existing fish community structure as well as the size structure of the different species populations present. Such a study could be conducted for approximately $10,000 to $15,000.

Biomanipulation would require filing an NOI with the Town Conservation Commission and coordination with NHESP to ensure rare species are not significantly impacted. The costs of permitting would be expected to be $5,000 to $7,000.

Implementation costs for biomanipulation vary significantly by approach. However, the primary costs associated with implementation are associated with monitoring to track the progress of the biomanipulation program and recommend any necessary changes or further stocking.

6.7 Nutrient Inactivation (Optional)

The results of this study, including the external data sources reviewed, indicate that water clarity in White Pond rarely drops below 3.0 meters (10.0 feet). The last time this was observed was in June and July 2006 (Whitepond.org 2014 and Walker 2014). Before that, the only time water clarity dropped below 3.0 meters was during spring of 1996, when clarity fell to 1.6 meters (5.25 feet), the lowest measurement observed at White Pond.

Additionally, the dates of algae blooms appearing in the Whitepond.org (2014) data record do not appear to directly correspond to reductions in water clarity. For example, an algae bloom observed at White Pond in September 1987 was qualitatively described as “lots” but it does not appear to have impacted quantitative measurements of water clarity, which ranged between 6.7 and 7.0 meters (22.0 and 23.0 feet) from late August to late September (although clarity had dropped as low as 3.0 meters [10.0 feet] in July 1987). A subsequent algae bloom in July 1988 was associated with water clarity measurement between 5.0 and 5.6 meters (16.5 and 18.5 feet). According to observational notes, the bloom conditions tend to be most visible in the northwestern cove of the pond, which may explain why clarity is rarely impacted at the measurement site (deep hole).

Although most algae blooms reported were short-lived (typically a few days) or of limited aerial extent, some longer-lasting or larger blooms were described in the data record (Whitepond.org 2014). When these conditions develop, it may be desirable to have treatment options available, Application of copper-based algaecides can quickly restore water clarity by killing off the algae itself. However, these algaecides do not address the root cause of the bloom which is usually excess availability of nutrients.

An alternative to application of copper-based algaecides is nutrient inactivation. Unlike copper treatments, nutrient inactivation does not directly kill algal cells. Rather it acts as a flocculent, removing suspended sediments and algal cells from the water column. It also binds to dissolved phosphorus, a primary form of nutrient driving excess algal growth, allowing it to precipitate out of the water and settle into the pond sediments where it is less or not available to algae.

Nutrient inactivation typically involves the addition of alum (aluminum sulfate), polyaluminum chloride, iron(III) chloride or similar aluminum-based compounds. In its simplest form, nutrient inactivation is conducted by applying alum directly to the pond as a single dose. More sophisticated programs involve proportional injection of alum into stormwater sources or tributaries so that phosphorous is intercepted before it even enters the pond.

Compounds such as alum have some demonstrated effect on internal nutrient cycling but must be expertly applied and buffered to be effective while avoiding large pH swings and consequent collateral damage to sensitive organisms, such as fish and native mussels.

One new product that does not impact pH and appears to be essentially non-toxic consists of a blend of the rare metal lanthanum with bentonite clay (trade name Phoslock). This product is now registered for use in much of the United States but must be applied by a professional. The price for nutrient inactivation with the lanthanum/bentonite mixture is higher than traditional buffered alum and, although it has been marketed as a safer, longer-lasting alternative to alum, the additional benefits are not yet clear.

Nutrient inactivation is currently recommended only as an alternative management action if recurring algae blooms become severe enough to restrict recreational opportunities or create a public health nuisance due to increased in-pond phosphorus. Given the level of phosphorus currently in White Pond sediments, long-term nutrient inactivation is not likely to be necessary in the near future. Therefore, it is anticipated that a nutrient inactivation project would more likely take the form of a low-dose surface application, intended to strip phosphorus from the water column and control algae blooms for a single season.

A nutrient inactivation project at White Pond would require filing an NOI with the Town Conservation Commission and coordination with NHESP to ensure rare species are not significantly impacted by the treatment. The costs of initial study, design and permitting would be expected to be $7,000 to $10,000, followed by approximately $5,000 to $30,000 per treatment for implementation. The variation in the cost of treatment is due to uncertainty in the dosage that would be needed, materials costs and any special conditions imposed by the Conservation Commission or NHESP during permitting.

6.8 No-action Alternative

Taking no action to manage White Pond and its watershed could result in eventual degradation of water quality, particularly if public recreational pressure on the pond significantly increases or further watershed development occurs in the identified high-impact locations. If water quality is reduced enough, summer trout habitat volume could shrink to the point where holdover trout will no longer be a realistic expectation and algae blooms would become more frequent and intense. Similarly, if preventative actions are not taken, the successful introduction and establishment of one or more aquatic invasive species could also occur. Depending on the species introduced, the changes to water quality and recreational opportunities in the pond could be significant.

Although this option does have the advantage of requiring no direct monetary costs, it may have a significant cost in the form of reduced aesthetic, recreational, water quality, water quantity and/or ecological value. Some of this cost may be intangible; however, lowered waterfront property values resulting from the degradation of White Pond may eventually result in real monetary costs to the Town and its residents. Taking no action now to prevent problems from developing at White Pond may end up costing much more in the long term. Therefore, the no-action alternative is not recommended.

Using the recommendations presented in this plan to guide appropriate corrective and preventative actions will help to preserve the value of White Pond as a community resource for years to come.

7.0 MONITORING PROGRAM

White Pond benefits from an extant volunteer monitoring program that has developed a fairly continuous and long-term dataset. This kind of citizen science provides invaluable insight into the nature of short- and long-term trends in water quality and pond water levels. It also helps to foster awareness of, interest in and advocacy for White Pond. As such, the continuance of a volunteer monitoring program is strongly recommended.

Given the records of and concerns with algae blooms, it may be worthwhile to add phytoplankton sampling to the existing monitoring program. An algae monitoring program could be developed for White Pond to quantify abundance and species composition of phytoplankton.

White Pond would also benefit from a periodic update of the management plan. The update would use monitoring data to evaluate the degree of success achieved by the management program. Adjustments would be made, as needed, to fine tune the management program and to address new challenges before they grow out of control.

A cost-effective phytoplankton monitoring program, with quarterly sampling in spring and fall and bi-weekly monitoring in the summer months, could be implemented for $6,000 to $7,000 a year, including collection and laboratory analysis of the samples.

If more detailed tracking of water levels in the pond is desired, a pressure transducer (water level meter) could be installed at depth in a sheltered location. This would allow continuous recording of water elevation in the pond. Basic models can be obtained at a nominal cost, typically less than $1,000 for the equipment itself and are built to last for two to three years of operation. These models would require occasional monitoring to inspect the equipment and download the data. More advanced models can be configured to transmit data wirelessly but are more expensive, usually several thousand dollars. Professional installation and survey of the equipment (for vertical control) could be accomplished for $3,000 to $4,500. Technical assistance with data manipulation and analysis on an annual basis could be added in to an existing monitoring program for approximately $1,500.

Annual review of citizen science data and updates to the management plan by a Certified Lake Manager could be completed for $3,500 to $4,500 per year.

8.0 POTENTIAL NUTRIENT LOADING IMPACTS OF EXPANDED RECREATION AT WHITE POND

Swimming

Based on direct observations made as part of this study and community input, including video documentation of recreational activities on a summer day, the current average number of swimmers in White Pond was estimated to be 100 people per day during the summer months. If the Town elects to develop a public swimming beach at Sachem's Cove, the number of swimmers in White Pond would logically be expected to increase. Similarly, if the proposed BFRT is completed as planned, the number of swimmers at Sachem's Cove would be likely to increase. It is difficult to determine exactly how many swimmers would be attracted to White Pond by the development of a public swimming beach or completion of Phase 2C of the BFRT. However, the degree of potential impact may be evaluated by assuming a conservative scenario and examining the corresponding increase in phosphorus loading.

In their analysis of Walden Pond, Colman and Friesz (2001) estimated a phosphorus input of 0.0405 g per swimmer. At Walden Pond, they estimated a total of 216,000 swimmers per year, resulting in an annual swimmer-generated phosphorus load of 8.7 kg/year for a pond with a total volume of 113 million cubic feet. At White Pond, an average of 100 swimmers per day during June, July and August (9,200 swimmers per year) yields an annual swimmer-generated phosphorus load of 0.4 kg/year for a pond roughly two-fifths the size (a total volume of 47 million cubic feet).

White Pond currently hosts far fewer swimmers per year than Walden Pond and is unlikely to approach the number of visitors that Walden Pond does. However, under the conservation scenario where traffic on the BFRT approaches 1,000 users per day, as observed on weekends in existing segments (Friends of the Bruce Freeman Rail Trail 2014) and that 50 percent of those using the BFRT will leave the trail to swim at White Pond, 46,000 swimmers could be expected over the June to August period. Using Cole and Friesz's (2001) estimate of 0.0405 g per swimmer, 1.9 kg of phosphorus loading could be expected from swimming on an annual basis. If realized, this would increase total phosphorus loading to White Pond from an estimated 13 kg/year to approximately 15 kg/year. This represents close to a 15 percent increase in phosphorus loading over current levels. Although this would not likely represent a significant increase to the pond as a whole, close monitoring of in-pond water quality would be highly recommended so that appropriate management adjustments could be made in response to any observed declines in water quality.

As evidenced by current patterns of swimming from Town land, Sachem's Cove would be likely to attract a higher volume of users. Although surface and ground water provide some degree of flushing of this cove, the shallow bathymetry and wind-protected setting may allow bacteria or algae to become temporarily concentrated in this area, if sources are present. Therefore, supplemental monitoring of key water quality parameters in this area would be useful (Section 7.0). Additionally, mitigation measures to minimize the potential phosphorus inputs by additional visitors are strongly encouraged.

Trail Use

Additional traffic on the trails to White Pond due to the opening of a public swimming beach or direct access from the BFRT could exacerbate erosion and result in additional mobilization of sediments and nutrients (especially phosphorus) into White Pond. If not properly managed, unrestricted access to the pond would lead to increased erosion. Currently, eroded areas are estimated to contribute 1.82 kg/year of phosphorus, or 14 percent of the total load even though they only represent a tiny fraction of the watershed area (0.1 percent). Therefore, even small increases in the area of erosion have the potential to result in much larger impacts to nutrient loading into the pond. However, this can be controlled with management of the trail system to direct foot traffic away from high slopes or otherwise vulnerable locations.

In response, it is recommended that access to the connecting and unblazed trails near currently eroding slopes along the White Pond shoreline (Figure 11) be suspended. Closures may be indicated using signage, fencing, maps, the Town website and/or social media. In some cases, installation of erosion controls may allow these areas to be reopened to trail traffic, possibly subject to restrictions, at a future date. In other areas, permanent closure and revegetation may be the more appropriate solution.

Where permanent decommissioning of a trail is desired, regrading and revegetation with native plants are recommended, at a minimum (DCR 2014). Popular trails may also require barrier fencing, at least in the short term. However, wire fencing is used as a permanent barrier on popular trails at Walden Pond State Reservation (DCR 2013).

With regard to the BFRT, it may be possible to direct foot and bicycle traffic from the BFRT to White Pond via surface roads, rather than permitting direct access over the sensitive trails on the western side of the White Pond Reservation. Although it would not negate the need to improve management of existing trails, this would allow for public access from the BFRT while focusing traffic into better established access locations, such as the public access boat ramp and the Varick Street entrance to White Pond Reservation and conservation land.

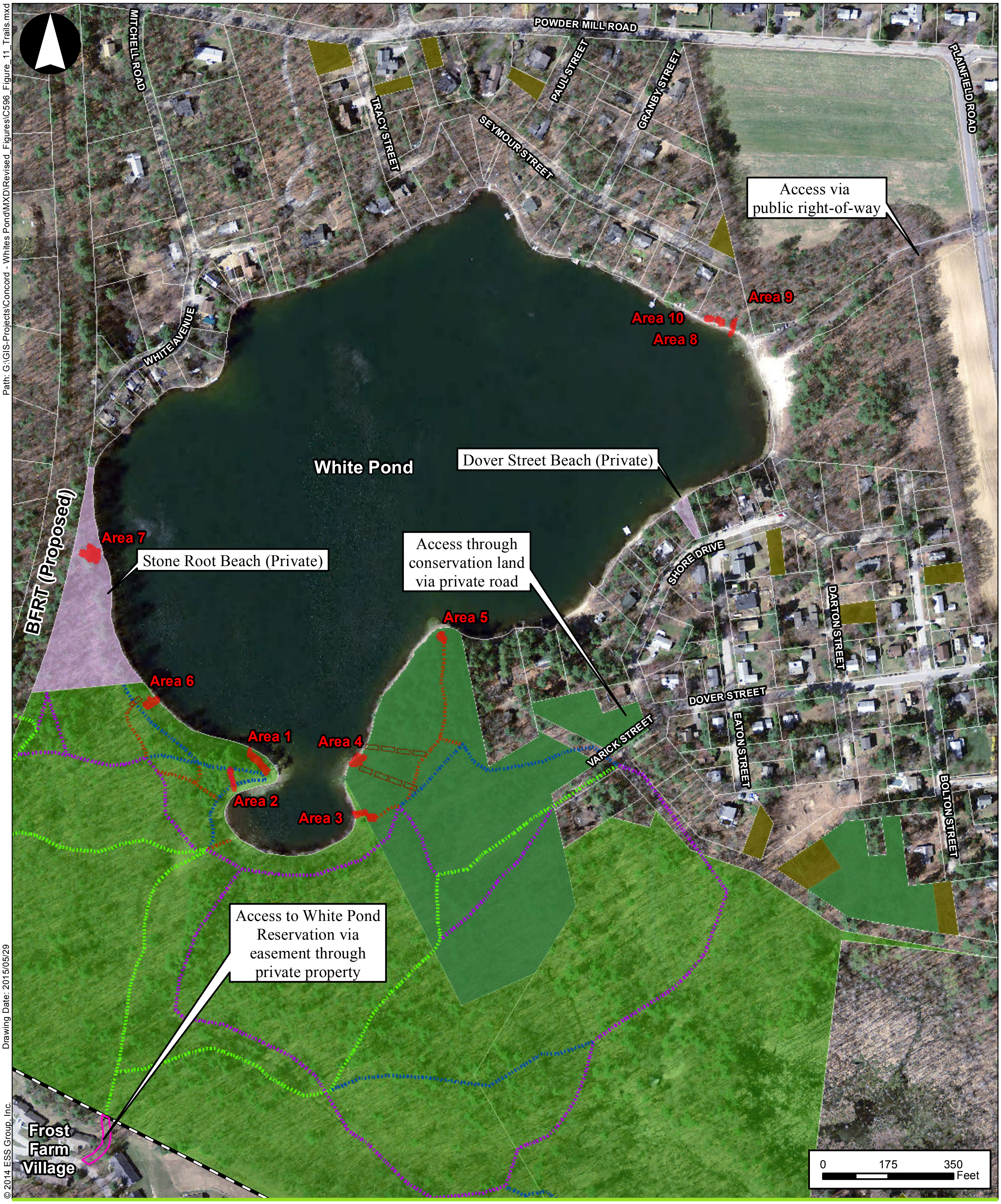
Domestic animals, such as dogs and horses, may also exacerbate nutrient and sediment loading through trampling of vegetation, trail wear and (if allowed on the beach) through direct urination or defecation into the pond. If the Town were to develop a public beach at Sachem's Cove, elevated bacteria levels would also be problematic. To address this issue, the Town could consider an ordinance or regulation prohibiting domestic animals (primarily dogs and horses) in White Pond Reservation and on conservation land. However, without enforcement, this restriction would likely have little impact.

Ultimately, the White Pond Reservation and adjacent conservation land would benefit from a Trail Management Plan to address each of these issues in more detail (see Section 6.2).

9.0 CONCLUSIONS

Water quality in White Pond still appears to be in very good to excellent condition. Given the small ratio of the watershed to pond area (less than three to one), future pollutant loading to the pond can be managed without the requirement for extreme measures and costs.

Path: G:\GIS-Projects\Concord - Whites Pond\MXD\Revised_Figures\C596_Figure_11_Trails.mxd



Drawing Date: 2015/05/29

ESS group
environmental consulting & engineering services

White Pond
Concord, Massachusetts

1 inch = 350 feet

Source: 1) Town of Concord, Trail Map and Parcels, 2010
2) USGS, Aerial Imagery 0.3m, 2013

Legend

Trails
- Main
- Secondary
- Connecting
- Unblazed
- Steps
- Eroded Areas
- White Pond Reservation
- Town Conservation Land
- Other Town Lands
- Private Access
- Public Easement (aprox. 20ft wide)
- Town Boundary

White Pond Access Network

Figure 11

The most critical management action identified through this study is the need to address the unchecked areas of bank erosion where they occur adjacent to White Pond. This includes the large Town parcels on the southwestern margin of the pond, as well as privately owned lands along the western and northeastern shorelines. Further improving the management of stormwater along the public access road and at the boat launch are also expected to address a small but significant portion of phosphorus sources.

Although addressing slope erosion and stormwater from impervious surfaces are expected to result in real improvements to pollutant loading rates at White Pond, additional management actions will be required to preserve water quality, aesthetics and ecological value for the long term. To this point, careful management of public access, public education and outreach, and regular monitoring will play key supporting roles in ensuring White Pond remains a community treasure. In particular, a combination of trail management and access restrictions will greatly benefit the pond by preventing future problems with slope erosion. Furthermore, as new local and regional recreational amenities and alternative uses of Town lands are evaluated, it will be important to consider ways to minimize the negative impacts of these projects on White Pond's valuable resources.

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11.0 GLOSSARY OF LIMNOLOGICAL TERMS

Abiotic: A term that refers to the nonliving components of an ecosystem (e.g., sunlight, physical and chemical characteristics).

Algae: Typically microscopic plants that may occur as single-celled organisms, colonies or filaments.

Anoxic: Greatly deficient in oxygen.

Aquifer: A water-bearing layer of rock (including gravel and sand) that will yield water in usable quantity to a well or spring.

Aquatic plants: A term used to describe a broad group of plants typically found growing in water bodies. The term may generally refer to both algae and macrophytes, but is commonly used synonymously with the term macrophyte.

Bacteria: Typically single celled microorganisms that have no chlorophyll, multiply by simple division, and occur in various forms. Some bacteria may cause disease, but many do not and are necessary for fermentation, nitrogen fixation, and decomposition of organic matter.

Bathymetric Map: A map illustrating the bottom contours (topography) and depth of a lake or pond.

Best Management Practices: Any of a number of practices or treatment devices that reduce pollution in runoff via runoff treatment or source control.

Biomass: A term that refers to the weight of biological matter. Standing crop is the amount of biomass (e.g., fish or algae) in a body of water at a given time. Biomass is often measured in grams per square meter of surface.

Biovolume: Analogous to biomass but expressed in terms of volume rather than mass.

Biota: All living organisms in a given area.

Chlorophyll a: A pigment used by higher plants and certain algae for photosynthesis. Measuring the level of this pigment in surface water is one way of describing the productivity of a pond and determining its trophic state (see Eutrophic).

Cultural Eutrophication: The acceleration of the natural eutrophication process caused by human activities, occurring over decades as opposed to thousands of years.

Ecosystem: An interactive community of living organisms, together with the physical and chemical environment they inhabit.

Endangered/Threatened Species: An animal or plant species that is in danger of extinction and is recognized and protected by state or federal agencies.

Epilimnion: In a thermally stratified lake, refers to the warmer, well-mixed upper layer of water.

Erosion: A process of breakdown and movement of land surface that is often intensified by human disturbances.

Eutrophic: A trophic state (degree of eutrophication) in which a lake or pond is nutrient rich and sustains high levels of biological productivity. Dense macrophyte growth, fast sediment accumulation, frequent algae blooms, poor water transparency and periodic oxygen depletion in the hypolimnion are common characteristics of eutrophic lakes and ponds.

Eutrophication: The process, or set of processes, driven by nutrient, organic matter, and sediment addition to a pond that leads to increased biological production and decreased volume. The process occurs naturally in all lakes and ponds over thousands of years.

Exotic Species: Species of plants or animals that occur outside of their normal, indigenous ranges and environments. Populations of exotic species may expand rapidly and displace native populations if natural predators, herbivores, or parasites are absent or if conditions are more favorable for the growth of the exotic species than for native species.

Filamentous: A term used to refer to a type of algae that forms long filaments composed of individual cells.

Groundwater: Water found beneath the soil surface and saturating the layer at which it is located.

Habitat: The natural dwelling place of an animal or plant; the type of environment where a particular species is likely to be found.

Herbicide: Any of a class of chemical compounds that produce mortality in plants when applied in sufficient concentrations.

Hypolimnion: In a thermally stratified lake, refers to the cooler, poorly-mixed lower layer of water.

Hypoxic: Lacking sufficient dissolved oxygen to support all but the most tolerant species.

Infiltration Structures: Any of a number of structures used to treat runoff quality or control runoff quantity by infiltrating runoff into the ground. Includes infiltration trenches, dry wells, infiltration basins, and leaching catch basins.

Invasive: Spreading aggressively from the original site of planting.

Isopach Map: A map illustrating the thickness of sediments within a lake or pond.

Limnology: The study of lakes.

Littoral Zone: The shallow, highly productive area along the shoreline of a lake or pond where rooted aquatic plants grow.

Macroinvertebrates: Aquatic insects, worms, clams, snails and other animals visible without aid of a microscope. They supply a major portion of fish diets and are important consumers of detritus and algae.

Macrophytes: Macroscopic vascular plants present in the littoral zone of lakes and ponds.

Metalimnion: The transitional region in a stratified lake, located between the epilimnion and hypolimnion. Often used interchangeably with thermocline.

Mixis: The mixing of vertically stratified lake waters. In most northern lakes, mixis typically occurs at least twice a year. Mixis is caused by seasonal changes in surface temperatures that affect the density of water. In some ponds, particularly those that are shallow, mixis may also be spurred by windy or wet weather. Used interchangeably with turnover.

Morphometry: A term that refers to the depth contours and dimensions (topographic features) of a lake or pond.

Nonpoint Source: A source of pollutants to the environment that does not come from a confined, definable source such as a pipe. Common examples of nonpoint source pollution include urban runoff, septic system leachate, and runoff from agricultural fields.

Nutrient Limitation: The limitation of growth imposed by the depletion of an essential nutrient.

Nutrients: Elements or chemicals required to sustain life, including carbon, oxygen, nitrogen and phosphorus.

pH: An index derived from the inverse log of the hydrogen ion concentration that ranges from zero to 14 indicating the relative acidity or alkalinity of a liquid.

Photosynthesis: The process by which plants use chlorophyll to convert carbon dioxide, water and sunlight to oxygen and cellular products (carbohydrates).

Phytoplankton: Algae that float or are freely suspended in the water.

Pollutants: Elements and compounds occurring naturally or man-made introduced into the environment at levels in excess of the concentration of chemicals naturally occurring.

Secchi disk: A black and white or all white 20 cm disk attached to a cord used to measure water transparency. The disk is lowered into the water until it is no longer visible (Secchi depth). Secchi depth is generally proportional to the depth of light penetration sufficient to sustain algae growth.

Sediment: Topsoil, sand, and minerals washed from the land into water, usually after rain or snowmelt.

Septic system: An individual wastewater treatment system that includes a septic tank for removing solids, and a leachfield for discharging the clarified wastewater to the ground.

Siltation: The process in which inorganic silt settles and accumulates at the bottom of a lake or pond.

Stormwater Runoff: Runoff generated as a result of precipitation or snowmelt.

Temperature Profile: A series of temperature measurements collected at incremental water depths from surface to bottom at a given location.

Thermal Stratification: The process by which a lake or pond forms several distinct thermal layers. The layers include a warmer well-mixed upper layer (epilimnion), a cooler, poorly mixed layer at the bottom (hypolimnion), and a middle layer (metalimnion) that separates the two.

Thermocline: A term that refers to the plane of greatest temperature change within the metalimnion. Often used interchangeably with metalimnion.

TKN: Total Kjeldahl nitrogen, essentially the sum of ammonia nitrogen and organic forms of nitrogen.

TSS: Total suspended solids, a direct measure of all suspended solid materials in the water.

Turbidity: A measure of the light scattering properties of water; often used more generally to describe water clarity or the relative presence or absence of suspended materials in the water.

Turnover: See mixis.

Vegetated Buffer: An undisturbed vegetated land area that separates an area of human activity from the adjacent water body; can be effective in reducing runoff velocities and volumes and the removal of sediment and pollutant from runoff.

Water Column: Water in a lake or pond between the interface with the atmosphere at the surface and the interface with the sediment at the bottom.

Water Quality: A term used to reference the general chemical and physical properties of water relative to the requirements of living organisms that depend upon that water.

Watershed: The surrounding land area that drains into a water body via surface runoff or groundwater recharge and discharge.

Zooplankton: Microscopic animals that float or are freely suspended in the water.